Hardwood Natural Regeneration

Moderator:

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OAK REGENERATION USING THE TWO-AGE SYSTEM

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Abstract-The two studies presented in this paper were completed in southeastern Kentucky and were designed to evaluate acorn production and development of advanced white oak reproduction from fully released white oak (*Quercus alba*) trees typical of reserve trees in the two age system. Twelve 2 acre 60- to 90-year-old white oak dominated stands were randomly assigned 1 of 3 treatments including an uncut treatment, and two cut treatments of 20 fully released canopy trees per acre, and 34 trees per acre. Acorn production from 11 to 15 years and regeneration accumulation, canopy cover and light regimes were monitored 15 years after treatment. Released trees produced significantly ($p < 0.01$) more acorns (1,424 grams per tree per year) compared to unreleased trees (689 grams per tree per year). Highly significant differences ($p < 0.001$) were found among treatments for cumulative white oak advanced regeneration density, height and densitometer readings. Strong relationships between densitometer readings and: PPFD; regeneration density; and regeneration height were found (R^2=ranging 0.743 to 0.974). The results of this study indicate that reserve white oak trees can provide for the recruitment of advanced oak regeneration and maintenance of light levels using easily applied crown densitometer readings can enhance the development of advanced regeneration required for the long-term maintenance of this species after future regenerative treatments.

INTRODUCTION

By definition the two age system maintains two distinct age classes throughout the majority of the rotation and is initiated by treatments which retain a limited number of canopy trees (reserve trees) along with a cohort of younger regenerating stems (Nyland 1996). Typically the two age stand is produced using a deferment cut where a limited number of reserve trees, occupying 10-30 ft^2 of basal area per acre, are selected from the overstory and retained for a second rotation while the remaining stems are removed (Stringer 1998). The number and distribution of the reserve trees must be such that as they produce little short- or long-term effect on regeneration and the development of the younger age class (Miller and Schuler 1995). Often times the stand, with the exception of the reserve trees, is subject to site preparation operations similar to clear cutting. This results in two distinct age classes, the older reserve trees and the younger regenerating cohort. While this system has been often termed shelterwood with reserves or irregular shelterwood the term shelterwood is misleading because the reserve trees are not intended to provide any sheltering effect to the regeneration.

This method has been used as an aesthetic alternative to clearcutting and as a means of potentially developing a limited number of large diameter high value sawtimber trees in a stand (Sims 1992; Smith and others 1989). The system also has structural and habitat advantages compared to clear cutting (Beck 1986; Miller and others 1995). Regardless of the objective, reserve trees in deferment cuts must be of proper vigor, landscape position, species, age, and potential tree grade so that they will survive and provide a viable product after two rotations. Not all stands and species can be managed using the two age system. Species which are relatively long lived and are commercially important make good candidates for reserve trees.

Besides the aesthetic and habitat values that two-aged stands have compared to clear cut stands they can be used to "life boat" species which do not have viable reproductive life forms at the time of cutting. A traditional clearcut essentially stops sexual reproduction in the stand for a substantial portion of the rotation and can limit the potential for the development of viable advanced regeneration. The reserve trees in the two age system provides for the potential for continued sexual reproduction in the stand and the ability to develop advanced regeneration which can be manipulated prior to the second regeneration cut. The maintenance of sexual reproduction throughout a rotation or a significant portion of it may be important for sporadic producers such as oak species. This paper presents the results of two studies conducted on the same study area. The first study was designed to determine acorn production from fully released small sawtimber white oak (*Quercus alba*) trees. The second study was designed to determine whether stands containing only a limited number of released white oak canopy trees could initiate the development of advanced regeneration.

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METHODS

This paper reports both the acorn production between 12 and 15 years of fully released white oak trees and the 15 year cumulative development of new seedlings and advanced regeneration in stands retaining a limited number per acre of fully released canopy white oaks. The study site was located at Robinson Forest, the University of Kentucky research and demonstration forest located in Cumberiand Plateau Physiographic Province in southeastern Kentucky. While this study was initiated as a growth and yield study for crop tree management of small sawtimber white oak stands (Stringer and others 1988) the full crown touching release and the relative numbers of crop trees in these stands (within the range recommended for two age reserve trees) provided an excellent opportunity for the determination of some of the regeneration dynamics associated with stands managed under a two age system. In 1983 twelve 2 acre 60- to 90-year-old white oak dominated stands were selected for study. In 1983 each stand was randomly assigned one of 3 treatments including an uncut treatment, a treatment leaving only 20 canopy trees per acre, and one leaving only 35 canopy trees per acre. The treatments were imposed by full crown touching release of selected canopy trees. These trees were of average dbh for co-dominant and dominant trees in these stands. One-half acre growth and yield plots were established in the middle of each treated stand. Trees > 2.54 cm dbh were tagged and survival and growth monitored and ten 1/100th acre regeneration plots were also randomly established in each growth and yield plot. In 1994, three reserve canopy trees were randomly selected in each growth and yield plot and 3 one meter square acorn traps (David and others 1998) were randomly placed under the crown of each tree. Acorns were collected from traps at two week intervals during the fall of 1994 through 1997. Total acorn mass was determined for each tree and pooled by treatment for analysis.

Final white oak regeneration measurements were taken during July 1997 and included the number and height of each white oak stem established after treatment. To provide a relative gauge of canopy light interception and the light environment at each regeneration plot a concave spherical crown densitometer™ (Forestry Suppliers, Inc. 24 quarter inch cross hairs) reading was taken at plot center. Data was recorded and is expressed in this paper as the number of cross-hairs where open sky was observed. At the same time a series of five photosynthetic photon flux density (PPFD) measures (μmol/meter²s PAR) were taken at a height above ground equal to the average height of the advanced regeneration (30 centimeter) at every other plot center using a quantum sensor (LI-COR, Inc.) and the values averaged by plot. All PPFD and densitometer readings were taken under clear sky conditions. White oak advanced regeneration data were pooled by treatment and subjected to statistical analysis using ANOVA and LSD(t) to determine treatment effects. Simple linear regression was used to establish the relationship between PPFD (dependent variable) and densitometer reading (independent variable) and advanced regeneration height (dependent variable) and densitometer reading (independent variable) pooled over all treatments. The Levenberg-Marquardt algorithm was used to establish best-fit coefficients of nonlinear functions for regeneration density (dependent) and densitometer reading (independent) pooled over all treatments.

Table l-Density and height of *Quercus alba* advanced regeneration in two age stands[a]

	density (no./ha)	height (cm)	densitometer reading
uncut	227b	19.8b	5.72c
20 per acre	930a	35.0a	7.16a
35 per acre	450b	29.9a	6.47b

[a] Values with different letters are significantly different ($p < 0.01$) using ANOVA and LSD(t).

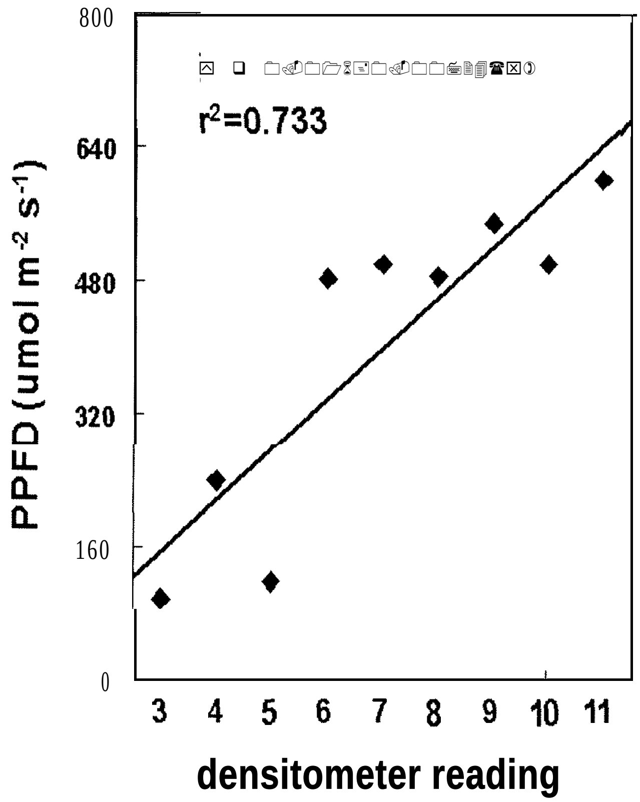

Figure l-Data points represent average PPFD for each densitometer reading. The line represents a positive linear relationship ($y = 0.016 + 0.00724(x)$, R^2=0.733) between densitometer reading and PPFD.

RESULTS AND DISCUSSION

There was no significant difference ($p > 0.05$) among annual acorn yields of the 20 and 35 tree per acre treatments and data were pooled for comparison with the uncut treatment. Analysis of released treatments vs. uncut (unreleased) treatment showed a highly significant difference ($p = 0.008$) in acorn yield (as expressed on a per

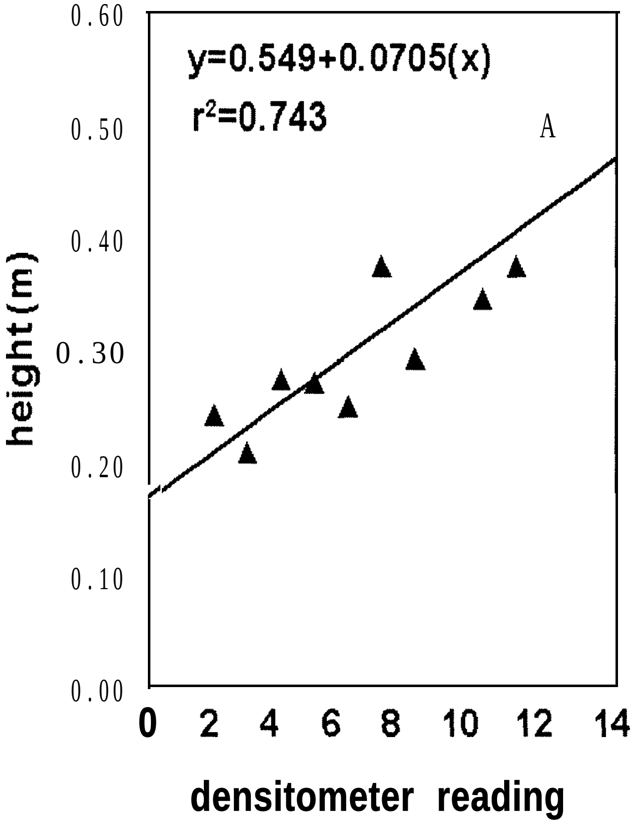

Figure 2-Data points represent average *Quercus alba* advanced regeneration stem density for each densitometer reading. The line represents an exponential relationship between densitometer reading and regeneration density (y = 43.615 + 22.373*exp(-x/-2.489), R^2=0.974).

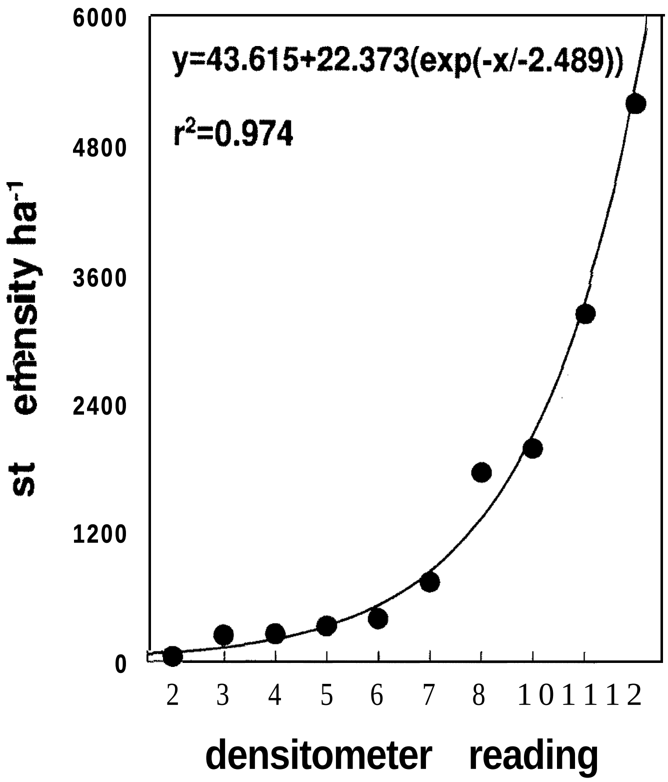

Figure 3-Data points represent average *Quercus alba* advanced regeneration height for each densitometer reading. The line represents a linear relationship between densitometer reading and regeneration height (y=0.549+0.0705(x), R^2=0.743).

tree basis). Released trees annually averaged 1,424 grams of acorns per tree compared to 689 grams per tree for unreleased trees. This indicates that fully released trees, typical of those that would be retained as reserve trees in deferment cuts in white oak dominated stands, have the capability of not only maintaining but improving acorn yield, a prerequisite for the development of advanced regeneration in two aged stands.

Highly significant differences ($p < 0.001$) were found among treatments for white oak advanced regeneration density, advanced regeneration height, and densitometer readings (table 1). The 20 reserve tree per acre treatment developed twice the number of regenerating white oak trees as the other treatments over the 15 year measurement period. The height of the white oak regeneration established after the treatment was greater for both cut treatments compared to the uncut treatment. The average height of the regeneration is relatively small at this point in time and would not be expected to be competitive if the stands were regenerated with the advanced regeneration in this condition. It is probable that some form of manipulation will be necessary to develop high vigor advanced regeneration prior to a future regeneration harvest. However, the advanced regeneration that developed after treatment indicates that the reserve trees are providing viable propagules which are developing advanced regeneration for future manipulation and stand regeneration.

Densitometer readings were also higher for the cut stands compared to the uncut stands. A positive linear relationship (y = 0.016 + 0.00724(densitometer reading), R^2 = 0.733) was found between densitometer reading and PPFD indicating a relationship between measurable canopy density and light levels at advanced regeneration height (figure 1). A positive relationship was also found between densitometer reading and advanced regeneration height (figure 2) and densitometer reading and advanced regeneration density (figure 3). An exponential relationship was found between densitometer reading and regeneration density (y = 43.615 + 22.373*exp(-densitometer reading/-2.489), R^2 = 0.974) while a linear relationship existed between densitometer reading and regeneration height (y = 0.549+0.0705(densitometer reading), R^2 = 0.743).

The results of this study indicate that small sawtimber sized co-dominant reserve white oak trees are capable of maintaing acorn production and resulting in the production of advanced regeneration that will potentially aid in the long-term maintenance of this species after future regenerative treatments. A positive correlation between canopy density and regeneration height along with the positive correlation between canopy density and light level indicates that light levels developed from the treatments encouraged regeneration development. This data indicates dramatic increases in advanced regeneration density can be obtained when the combined understory, midstory, and overstory exhibit a densitometer reading greater than 6.

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OAK REGENERATION: FOUR YEARS AFTER THREE HARVESTING TREATMENTS IN A NORTH ALABAMA UPLAND HARDWOOD STAND

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Abstract-Fourth year regeneration of upland oaks (Quercus spp.) was compared within three harvesting treatments in the mountains of northern Alabama. Six four-acre experimental blocks were established on north facing slopes. Each of the three harvesting treatments (deferment cutting, strip clearcutting, and block clearcutting) was randomly assigned to two treatment blocks. Major oaks present were white oak (*Q. alba*), northern red oak (Q. rubra), and chestnut oak (*Q. prinus*). Densities and stocking levels of non-sprout origin non-overtopped oak reproduction were related to treatment, topographic position, and pre-harvest competition cover. The overall contribution of the non-sprout oak regeneration was low. Post harvest germination and advance reproduction contributed equally to the successful fourth year reproduction.

INTRODUCTION

Oak-Hickory forests cover approximately 35 percent (7.7 million acres) of Alabama's timberland with 65 percent of the Oak-Hickory forests found in north Alabama (McWilliams 1992). Upland hardwood stands have been long viewed as valuable. Some of their values can easily be associated with economics, such as the sale of timber or the lease of hunting rights. Unfortunately placing an economic value on aesthetics or wildlife benefits can be difficult. Regardless of the rationale, upland hardwood stands are important and warrant the attention of individuals interested in maintaining and managing these diverse values.

"Oak regeneration is a problem and the problem is widespread. Many of the problems can be solved by utilizing information that is already available, but there is a cost involved, which will have to be addressed by forest managers and forest landowners. Other problems with oak regeneration will require a major research commitment" (Smith 1993a).

In 1996, a permanent study was established in the mountains of northern Alabama to assess the stocking and growth of oak regeneration following three harvesting treatments: block clearcutting, strip clearcutting and deferment cutting. This paper reports on data taken after the fourth full growing season (Fall 2000). This approximates the end of the stand initiation stage, at which point an inference can be made as to the composition of the mature stand.

OBJECTIVES

Two main objectives have been developed for this study: 1) to determine which potential factors had an effect on fourth year post-harvest stand composition: and 2) to investigate which of the studied silvicultural treatments (block clearcutting, strip clearcutting, and deferment cutting) provided for the desired and adequate oak regeneration component. The overall goal of this ongoing study is to identify the influences upon oak regeneration at various times after harvest.

METHODS

Study Site

The site is located in the Sandstone Mountain Forest Habitat Region of northern Alabama on the southern Cumberland Plateau physiographic province (Hodgkins and others 1979). Major ridges typically run east to west. This tract is currently owned and managed by International Paper and is adjacent to the William B. Bankhead National Forest in Lawrence County, AL. Slopes range from five to sixty percent.

The study is located in an upland mixed hardwood forest on north facing slopes and ridge shoulders. Prior to harvest, overstory (trees larger than 5 inches dbh) density was 313 stems per acre with a total basal area of 118.3 square feet per acre (table 1). The stand was composed of a mixture of oak species (*Quercus spp.*), sugar maple (*Acer sacharum*), black tupelo (*Nyssa sylvatica*), American beech (*Fagus* grandifola), and hickories (*Carya* spp.).

Study Design

Six four-acre treatment blocks (400 by 440 feet) were established on north facing slopes. Each of the three harvesting treatments was randomly assigned to two of the experimental blocks. The block clearcutting treatment administered was a silvicultural clearcut; all stems greater than 1.5 inches dbh were cut. The strip clearcutting treatment harvested all stems greater than 1.5 inches dbh in alternating one-acre cut and uncut strips approximately 120

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Table 1-Pre-harvest overstory composition, basal area, and advance reproduction and composition of fourth year non-overtopped reproduction, oaks and other species

Fourth year Species	Pre Harvest			
	Overstory[a]		Advance reproduction[b]	Non-overtopped reproduction[c]
	Ft²/acre	Stems/acre	Stems/acre	Stems/acre
L. tulipifera	9.7	7	2	882
A. saccharum	4.3	8	1229	492
Non-Comm	1.1	4	608	460
Other-Comm	10.7	16	182	404
N. sylvatica	4.4	9	281	363
A. rubrum	2.2	4	408	223
Fraxinus sp.	1.8	4	50	153
Carya sp.	29.0	36	177	131
Quercus sp.	46.6	40	212	112
F. grandifolia	8.5	10	196	52
Total	118.3	138	3345	3272
Q. alba	12.7	13	18	38
Q. rubra	8.5	6	113	32
Q. prinus	22.0	20	57	30
Other oaks[d]	3.4	1	24	12
Total	46.6	40	212	112

[a] Includes canopy trees greater than 5 inches dbh in the harvested areas only.
[b] AR greater than 1 foot tall and less than 1.5 inches dbh.
[c] Represents the 498 plots in the harvested areas.
[d] Mainly black (Q. *velutina*), southern red (Q. *falcata*), and scarlet oaks (*Q. coccinea*).

feet wide and roughly oriented with the contours. The deferment cuts were harvested in a similar fashion, except that a basal area of approximately 25 square feet per acre was left. The reserve trees were selected and marked based upon the criteria that they were evenly spaced, good quality co-dominant oaks (where possible), and more than likely to survive throughout the rotation. Where oaks were not present, other species meeting the criteria were marked and used as reserve trees.

Pre-Harvest Measurements

In 1996, prior to harvest the six treatment blocks were sampled by three 6.6-foot wide permanent belt transects equally spaced and running down slope. Each belt transect includes 67 milacre plots and makes up the center line of a 33-foot wide segment running east to west. This grid system runs the entire length of the block. Each odd numbered plot along the center line was established with metal conduit pipe marking the top corners and the lower boundaries were marked with pin flags. Each milacre plot was divided into quadrants to facilitate the re-measurement and successive counting of reproduction. Oak seedlings were tagged and measured in all quadrants. Counts of all non-oak tree reproduction, by species and size class, were obtained in each measurement plot at each inventory. Size classes were recorded as 1) less than 6 inches, 2) 6-12 inches, 3) 12-36 inches, 4) greater than 36 inches with a diameter less than 1.5 inches, or 5) with a dbh greater than 1.5 inches. Vegetative competition cover and site characteristics were also obtained. Ocular measurements for woody vegetative competition were made to the nearest 5 percent increment and later combined into classes of 0-10, 11-30, 31-70, and 71-100 percent. Overstory data was obtained for the entire one-half chain strip, which provided a 25 percent sample of the treatment blocks. Greater detail on the pre-harvest measurements can be found in Golden and others (1999).

Post-Harvest Measurements

Following the harvest in fall 1996, site and soil impacts were assessed and recorded for each measurement plot. Another detailed survey was conducted using the same procedures as the pre-harvest measurement. Fifteen months (Fall 1997) after harvest the stand was again re-entered and the plots re-located and re-measured, but these are not reported in this paper.

Fourth Year Measurements

In fall 2000, a fourth year re-measurement was conducted. Tagged oak reproduction was re-measured and new reproduction recorded. Non-oak reproduction was inventoried by species and competitive position. Competitive position was recorded as free to grow (FTG), crowded but not overtopped (CR), or overtopped (0). These classes were modified from Smith (1986).

Data Analyses

The data analyses reported in this paper are per acre and stocking comparisons within categories of treatment, topography, and pre-harvest competition cover. The values are derived from the tagged reproduction of non-sprout origin in non-overtopped competitive positions. Sprouts from stems larger than 1.5 inches dbh are not included. Since all oak seedlings were tagged and measured prior to harvest and at each subsequent measurement, a determination of origin could be made. Those seedlings present prior to harvest of any size were classified as advance reproduction (AR) and those seedlings germinating thereafter were classified as post harvest germination (PHG). All plots in the deferment cuts and block clearcuts were used. In the strip clearcuts, only plots in the harvested areas were used. All plots in all the treatments that were used totaled 498. Per acre values for non-oak reproduction were obtained from the non-tagged inventory.

All of the data analyses were accomplished using the Statistical Analysis System (SAS) version 6.12. Simple descriptive statistics were obtained using Proc Means and Proc Freq (SAS Institute Inc 1990).

RESULTS

Pre-Harvest Overstory Composition

The initial stand had 138 stems per acre, 30 percent oak (table 1). The basal area of canopy trees (5 inches and larger dbh) was 118.3 square feet per acre, with oaks the largest component at 39 percent. Of the oaks, chestnut oak (Q. *prinus*) was the most abundant with 50 percent of the total and a basal area of 22 square feet per acre. White oak (Q. *alba*) and northern red oak (Q. *rubra*) also comprised a significant portion of the pre-harvest stand. Remaining oaks were grouped together and classified as other oaks. Most of the oaks were 65-70 years old. From height and age measurements, oak site index was estimated as 70-80 feet (base age 50) on the ridge and upper slopes and 85-100 feet on the middle and lower slopes. Oak numbers were the highest on ridge shoulders and declined down the slope.

The pre-harvest subcanopy density (1.5 - 5 inches dbh) totaled 176 stems per acre. The most abundant species were sugar maple and American beech, which comprised 21 and 18 percent of the stems respectively. Most of the sugar maple and American beech were found on the lower slopes where they dominated the understory. The oaks averaged only 5 stems per acre. These were mainly chestnut oaks located on the ridge shoulders. The most abundant under. story species was American hornbeam (*Ostrya virginiana),* at 30 stems per acre (Golden and others 1999).

Advance reproduction

Large advance reproduction (AR), greater than 1 foot tall and less than 1.5 inches dbh, totaled 3,345 stems per acre (table 1). The oak component was low, making up 6 percent (212 stems per acre) of the total large AR. Northern red oak (113 stems per acre) was the most abundant, followed by chestnut oak (57 stems per acre) and white oak (18 stems per acre). Of the non-oak species, sugar maple was the most abundant with 1,229 stems per acre (37 percent), then non-commercial species with 608 stems per acre (18 percent), followed by red maple with 408 stems per acre (12 percent). The least abundant species was yellow poplar (*Liriodendron tulipifera*), with 2 stems per acre.

Fourth Year Non-Overtopped Composition

Overall densities for all species after four years are shown in table 1. Fourth year non-overtopped reproduction totaled 3,272 stems per acre, with the oaks comprising only 3 percent (112 stems per acre). White oak (38 stems per acre)

Table 2-Fourth year composition of non-overtopped oak reproduction in the harvested areas, within treatment, topographic location, and competition class

Factor	Plots	Q. *alba*	Q. *rubra*	*Q.prinus*	Other oaks	All oaks
		...Stems per acre...				
<u>Cuttina Treatments</u>						
Deferment cut	200	90	60	65	15	230
Strip clearcut	100	0	20	20	10	50
Block clearcut	198	5	10	0	10	25
Topographic Position						
Upper / ridge	121	140	74	74	25	314
Mid	192	5	10	21	5	42
Lower	174	6	29	11	11	57
Pre-Harvest Competition Cover						
O-10 pct	156	109	58	64	19	250
1 1-30 pct	253	8	16	20	8	51
31-70 pct	85	0	35	0	12	47
71-100 pct	4	0	0	0	0	0

was the most abundant, followed by nor-them red oak (32 stems per acre) and chestnut oak (30 stems per acre). Of the non-oak species the most abundant was yellow poplar, with 882 stems per acre (27 percent), then sugar maple with 492 stems per acre (15 percent). No other tree species was less abundant than the oak reproduction; American beech had 52 stems per acre, which is higher than any individual oak species count.

Among the harvesting treatments, the deferment cut had the most abundant total oak reproduction, 230 stems per acre (table 2). Of the three major oak species within the deferment cuts, white oak had the highest density (90 stems per acre) with no noticeable difference between northern red oak and chestnut oak. Non-overtopped oaks were scarce in the strip cuts and the block clearcuts (50 and 25 stems per acre respectively), with no obvious differences among major species. Among topographic classes, the upper slope and ridge shoulder positions had the highest non-overtopped oak densities (314 stems per acre). White oak was most abundant (140 stems per acre) on these positions, with no noticeable differences between chestnut and northern red oak. One obvious difference in the lower slope positions was the higher density of northern red oak (29 stems per acre). For the classification by competing vegetative competition cover, fourth year non-overtopped oak reproduction was highest in the O-l 0 percent competition class (250 stems per acre) and declined drastically with increased competition cover. White oak had the highest density (109 stems per acre) with no clear distinction between chestnut oak and northern red oak. In the 31-70 percent cover class, northern red oak had 35 stems per acre and white oak and chestnut oak were non-existent. No non-overtopped oak reproduction was established in the 71-100 percent cover class.

Fourth Year Non-Overtopped Stocking of Oaks

Stocking was defined on a plot-by-plot basis. Any plot that contained at least one oak stem in a non-overtopped competitive position was considered stocked. The overall stocking of oak reproduction was very low, only 9 percent (table 3). This extremely low level of stocking is an indication of the challenges faced by foresters and forest managers who want to perpetuate oaks as a major component of future stands.

Oak stocking was highest in the deferment cuts at 18 percent, and was only 5 and 3 percent in the strip and block clearcutting treatments respectively. Oak stocking was very low on all topographic positions, but highest on the ridge shoulders and upper slopes (22 percent). The middle and lower slope locations were stocked at only 4 and 6 percent respectively. There was no noticeable difference among the three major species within treatment and topographic position. Fourth year non-overtopped oak stocking was low at every pre-harvest competition level. The O-l 0 percent class had the highest stocking (15 percent) and the 71-100 percent class was un-stocked. The 1 l-30 and 31-70 percent classes were equally stocked at 6 percent. One noticeable difference among the three major species in the 31 -70 percent class was that chestnut oak was stocked at 5 percent while white oak and northern red oak were unstocked.

Origins of Fourth Year Non-Overtopped Oaks

Successful reproduction for this study is any stem that survived to the fourth year measurements and is in a non-overtopped competitive position. This section focuses on success related to origin. Fourth year non-overtopped reproduction was determined to have originated either from any size advance reproduction (AR) or from post harvest germination (PHG). Numbers of successful oak reproduction were very small. Of these small numbers, more than 50 percent of the non-overtopped overall oak reproduction originated from PHG (58 stems per acre). AR origin repro-

Table d-fourth year stocking of non-overtopped oak reproduction in the harvested areas, within treatment, topography, and competition classes

Factor	Plots	*Q.alba*	*Q. rubra*	*Q.prinus*	Other oaks	All oaks
		Percent stocked plots				
Cutting Treatment						
Deferment cut	200	5	6	6	2	18
Strip clearcut	100	0	2	2	1	5
Block clearcut	198	1	0	1	1	3
Topographic Position						
Upper / ridge	121	7	7	7	2	22
Mid	192	1	2	1	1	4
Lower	174	1	1	3	1	6
Pre-Harvest Competition Cover						
o-1 0 pct	156	5	3	6	2	15
1 1-30 pct	253	1	2	3	1	6
31-70 pct	85	0	0	5	1	6
71-100 pct	4	0	0	0	0	0
Overall	498	2	3	3	1	9

Table 4—Origins of fourth year non-overtopped oak reproduction in the harvested areas, within treatment, topography, and competition class

Factor	Plots	*Q. alba* AR	*Q. alba* PHG	*Q. rubra* AR	*Q. rubra* PHG	*Q. prinus* AR	*Q. prinus* PHG	Other oaks AR	Other oaks PHG	All oaks AR	All oaks PHG
		Stems per acre									
Cutting Treatment											
Deferment cut	200	35	55	15	45	45	20	10	5	105	125
Strip clearcut	100	0	0	10	10	10	10	10	0	30	20
Block clearcut	198	5	0	5	5	0	0	5	5	15	10
Topographic Position											
Upper / ridge	121	50	91	17	58	41	33	17	8	124	190
Mid	192	5	0	5	0	16	5	0	5	31	10
Lower	174	6	0	6	23	11	0	11	0	34	23
Pre-Harvest Competition Cover											
0-10 pct	156	38	71	13	19	45	19	13	6	109	115
11-30 pct	253	8	0	8	20	12	8	4	4	32	32
31-70 pc	85	0	0	12	35	0	0	12	0	24	35
71-100 pct	4	0	0	0	0	0	0	0	0	0	0
Overall	498	16	22	10	22	20	10	8	4	54	58

duction totaled only 54 stems per acre (table 4). The major oaks, white oak, northern red oak, and chestnut oak, originated at 58, 69, and 67 percent respectively, from PHG. Fourth-year oak stems that originated from stump sprouting are not included here, but will be addresses in another paper.

There was no clear difference in origin among harvesting methods for non-overtopped reproduction of all oaks. However, for the deferment cutting, white oak and northern red oak reproduction originated mainly from PHG (61 and 75 percent respectively). In contrast, 69 percent of the chestnut oak originated as AR. There was no notable difference among species within the strip clearcutting method. One clear difference in the block clearcutting treatments was that white oak originated 100 percent from AR. Among topographic positions, there was a notable difference in the origins of overall successful stems. The majority of all stems in the upper and ridge shoulder positions originated from PHG (61 percent), while mid slope (76 percent) and lower slope (60 percent) locations had most of the successful stems originating from AR. Among species, obvious differences among topographic positions existed. In the upper slope and ridge shoulder positions, white oak (65 percent) and northern red oak (77 percent) mainly originated from PHG, while chestnut oak (55 percent) originated from AR. In the mid slope positions all major oak species mainly originated from AR (white oak 100 percent, northern red oak 100 percent and chestnut oak 76 percent). The lower slope locations had 100 percent of the white oak and chestnut oak originating from AR, while the northern red oak (79 percent) originated mostly from PHG. There was no obvious difference in the origin of fourth year non-overtopped reproduction among pre-harvest competition cover classes for the overall successful stems. However, within competition classes there was a noticeable difference among major oak species. Within the O-10 percent competition class, the origin of successful white oak and northern red oak reproduction **was** noticeably higher from PHG (59 and 65 percent respectively). Conversely, the majority of chestnut oak reproduction came from AR (70 percent). Origins for white oak and chestnut oak in the 11-30 percent class are mainly from AR (100 and 60 percent respectively). In contrast, the higher percentage of northern red oak reproduction came from PHG (71 percent). The only species that had obvious differences in the 31-70 percent class was northern red oak, with 74 percent of the successful stems coming from PHG.

DISCUSSION

At only 112 non-overtopped stems per acre and 9 percent plot stocking, the oak component in the fourth year reproduction is severely reduced from that of the pre-harvest stand. It is generally accepted that large advance reproduction is necessary for successful regeneration of oaks (Sander and others 1984, Johnson 1993). It is also well established that obtaining adequate oak reproduction is more difficult on high quality sites, those greater than 70-foot site index (Smith 1993b). Overall this site presented problems in both areas. In the pre-harvest stand oak AR larger than 1 foot tall was quite low, only 212 stems per acre, and was lowest on the middle and lower topographic positions (Golden and others 1999). Site indexes were higher than 70 feet even on the upper slopes and ridge shoulders and exceeded 85 feet on the middle and lower slopes. Fourth year non-ovetiopped oak stocking and densities were low on all topographic positions, but highest on ridge shoulders and upper slope positions, which were relatively poorer, drier sites.

Fourth year non-overtopped oak densities and stocking declined in the order: deferment cutting, strip clearcutting, and then block clearcutting. A possible reason for this is the increase in logging disturbance in that same order (Dubois and others 1997, Golden and others 1999). Another possible explanation is the amount of canopy left. The impacts posed by the remaining canopy cover might be similar to a nurse tree effect or a shading effect. The leave trees in the deferment cut and edge trees in the uncut strips allowed the oaks to grow in the lightly shaded areas. Other faster growing species would have out competed the oaks if the canopy were completely removed. The origins of the fourth year non-overtopped white oak and northern red oak in the deferment cuts are mainly from PHG. Conversely, the major origin of chestnut oaks in the deferment cut was from AR. Chestnut oak can persist for many years in the understory on poorer quality sites and can react quickly to release (Burns and Honkala 1990). The higher percent of successful oak reproduction that came from PHG was surprising. However, it is possibly a reflection of the overall small AR numbers. Where the higher numbers of PHG were observed, the deferment trees remained and provided seed. In addition, white oak seed germinates in the fall and its acorns have a 50-90 percent germination capacity (Burns and Honkala 1990).

By the fourth year, a large amount of oak reproduction was overtopped by competing vegetation therefore not considered "successful". Sixty seven percent of the plots had pre-harvest competition cover exceeding 10 percent. Under this severe competition the slower growing oaks tend to fall behind. Once the canopy was fully removed, the faster growing species were able to out compete the majority of oak reproduction, overtopping it by age four.

CONCLUSIONS

Oak densities (112 stems per acre) and stocking levels (9 percent) were very low for all factors affecting fourth year non-overtopped reproduction from non-sprout origins. Oak densities and stocking percentages were highest in the deferment cutting treatments as compared to the strip and block clearcutting treatments. Higher numbers and stocking levels were also found at the upper slope and ridge shoulder positions and declined substantially on the middle and lower slope locations. As pre-harvest competition levels increased oak stocking and densities decreased. For all oaks approximately 50 percent of the fourth year non-overtopped reproduction originated from post harvest germination. The majority of white oak and northern red oak originated as post harvest germination. However, the majority of chestnut oak stems originated from advance reproduction. The contribution of the non-sprout oak regeneration to the future stand will be low. Reproduction from sprout origin will be assessed in a subsequent paper.

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STUMP SPROUTING 2 YEARS AFTER THINNING IN A CHERRYBARK OAK PLANTATION

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Abstract-Stump sprouts are considered an important regeneration source in hardwood management, especially in upland oak-dominated forests. Less is known about stump sprouting in bottomland oak forests. Therefore, the objective of this study was to determine the success and growth of stump sprouts following 2 thinning levels, 70-75 percent of initial stocking (light thinning) and 45-50 percent of initial stocking (heavy thinning) in a 35-year-old cherrybark oak (Quercus pagoda Raf.) plantation in Concordia Parish, LA. Two growing seasons after thinning, cherrybark oak sprout success was 37 percent across the study site, a 200 percent decrease from the previous year. A severe drought occurred during this time and may have contributed to the low sprouting success. Stumps averaged 8.5 sprouts over the 2-year study period, and dominant sprouts were 82 inches tall. Results from this study indicate that greater weights should be placed on stump sprout potential in bottomland hardwood regeneration evaluation models.

INTRODUCTION

Sprouts are generally defined as shoots arising from the base of woody plants or as suckers from roots (Helms 1998). Though called various names, tree sprouts can usually be divided into 3 types for management purposes: seedling sprouts, root sprouts, and stump sprouts. Seedling sprouts are stems that arise from existing or severed seedlings or saplings (53 inches dbh) where the root system may be several to many years older than the stem (McQuilkin 1975). Root sprouts, or suckers, arise from adventitious suppressed buds on root systems of existing or severed trees (Kormanik and Brown 1967). Stump sprouts arise from the base of severed stems and can appear anywhere from the top to the base of the stump.

Stump and root sprouts are considered one of three broad classes of oak reproduction (Aust and others 1985), the others being new seedlings that develop from acorns which germinated just before or soon after harvest and advance regeneration - older regeneration living underneath a forest canopy (Smith and others 1997). Advance regeneration and sprouts have long been considered the most important source of hardwood regeneration, especially for the various oak species (Hodges 1987, Johnson 1994). Sprout survival and development have been well-studied for a variety of upland oak species including northern red oak (Quercus *rubra* L.) (Johnson 1975, Johnson and Rogers 1980), black oak (*Q. velutina* Lam.) (Johnson and Sander 1988), white oak (Q. *alba* L.) (McQuilkin 1975, Lynch and Bassett 1987), and others (Cobb and others 1985, Lowell and others 1987). This information has been incorporated into several hardwood regeneration evaluation models designed to determine if sufficient density and stocking of oak regeneration exists prior to a harvest for regeneration success (Sander and others 1976, Johnson 1977, Sander and others 1984, Dey 1993, Dey and others 1996).

Less is known about the role of sprouting in the regeneration of bottomland oak species (Gardiner and Helmig 1997, Golden 1999). The stump sprouting component of bottomland hardwood regeneration evaluation models rely on the best information currently available, i.e., personal observations, results from upland oak sprouting research, and limited bottomland oak sprouting research (Johnson 1980, Johnson and Deen 1993, Hart and others 1995, Belli and others 1999). Therefore, the objective of this study was to add to the sprouting knowledge of bottomland oak species. Specifically, we examined success and growth of cherrybark oak (Q. pagoda Raf.) stump sprouts following two intensities of thinning in a 35-year-old plantation. Two-year results are reported.

MATERIALS AND METHODS

Study Site Description

The study site is located on the Red River Wildlife Management Area in Concordia Parish, east-central LA. Physiographically, the site is located in the Natural Levee Subregion, Mississippi River Floodplain Region of the Alluvial Floodplain Province (Evans and others 1983) and is protected from flooding by the mainline levee system. Soils are composed of Commerce silt loam (Aeric Fluvaquents) and Bruin silt loam (Fluvaquentic Eutrudepts). The former soil is deep and somewhat poorly drained while the latter soil is deep and moderately well drained. Rainfall averages 59 inches per year and is generally evenly distributed throughout the year although periodic summer droughts occur (Evans and others 1983). Average temperature is 67 degrees Fahrenheit with a high of 81 degrees Fahrenheit in July and August (Evans and others 1983). Cherrybark oak site index, base age 50 years, was estimated at 110 feet (Baker and Broadfoot 1979).

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The plantation was established on a 350-acre agriculture field during 1969-1972. Planting density was variable but averaged 411 seedlings per acre. Cherrybark oak planting accounted for 43 percent of the total area and was primarily located in one portion of the field.

Treatments

Fifteen, 1 .&acre rectangular plots (396 by 198 feet) were established in the cherrybark oak portion of the plantation. Each plot consisted of a 0.4-acre interior measurement plot (264 by 66 feet) with the remaining area as buffer. Diameter of all trees ≥ 5 inches dbh was measured in each interior plot and a hand-drawn map was made for the location of each tree for future reference. These data were used to determine initial stocking using Goelz's (1995) stocking guide for southern bottomland hardwoods. Plots were then blocked, 3 plots per block, by initial stocking to reduce pre-harvest variation among treatments. Overall stocking among the plots was 89 percent, with average stocking among the plots in each block ranging from 76 percent in the lightest stocked block to 104 percent in the heaviest stocked block.

Three thinning treatments were randomly assigned to the plots in each block. These treatments included a light thinning in which stocking was reduced 70-75 percent, a heavy thinning which reduced stocking to 45-50 percent, and an unthinned control. Tree marking guidelines were developed using the stocking information along with a tree class system (species, crown class, and butt-log grade) to determine those trees that would serve as future crop trees (preferred stock), those trees which could remain until the next thinning or could be marked for the present thinning (reserve stock), and those trees that should be removed in the present thinning operation (cutting stock) (Putnam and others 1960, Meadows 1996). All cutting stock trees were marked then reserve stock trees were marked as needed until the desired residual stocking was attained. Thinning operations were conducted from 30 September 1998 through 3 February 1999 across the plantation. A total of 141 cherrybark oak trees were harvested in the treatment plots.

Measurements

Assessments were made of each cherrybark oak stump during the 1999/2000 and 2000/2001 dormant seasons, representing the 1999 and 2000 growing seasons, respectively. Observations were noted as to whether the stump sprouted, how many sprouts were present, and the height of the tallest sprout (in centimeters) for each stump when 2 or more sprouts were present. Due to the prolifera-tion of sprouts in a small location on many stumps, only those sprouts that were ≥ 1 foot tall and located within 3 inches of the stump were counted. These criteria allowed us to distinguish sprouts from branches within a sprout and to avoid counting stems that paralleled the surface of the ground despite being as long as 3 feet. On dead sprouts, we noted if they had initiated growth prior to their death.

Analyses

Sprout success, calculated as the number of stumps with at least one living sprout divided by the total number of stumps, sprout numbers per stump, and height of the tallest sprout on each stump were analyzed using analysis-of-variance in a randomized complete block design. Initial stocking density represented the blocking factor. Since controls contained no stumps, only two treatments, light thinning and heavy thinning, were included in the analyses. Regression techniques were also used to determine if relationships existed between the variables and pre-harvest tree diameter. All analyses were done using PC-SAS (SAS 1985). An alpha level of 0.05 was used to determine significant differences. Height values were converted to English units for reporting purposes.

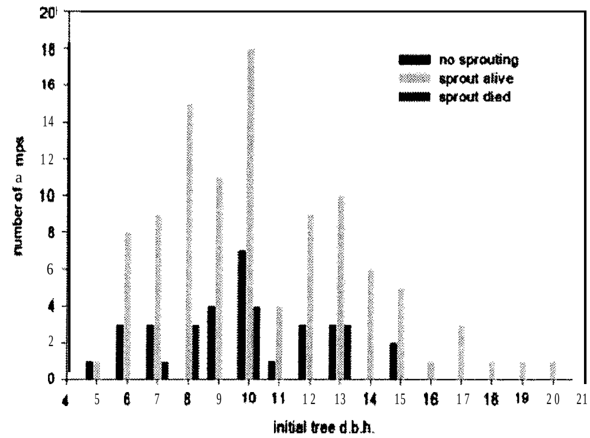

Figure l-1999 diameter distribution of cherrybark oak sprouting success for light and heavy thinning treatments on the Red River Wildlife Management Area, Concordia Parish, LA.

RESULTS AND DISCUSSION

Sprout Success

One growing season after thinning 81 percent of the cherrybark oak stumps had sprouted. Sprouting occurred for all diameter classes with nearly 100 percent sprouting for trees ≥ 14 inches (n = 20) (figure 1). Eleven of these sprouts died during the year for a sprouting success of 73 percent (table 1). Sprout success in the light thinning treatment was greater than in the heavy thinning treatment,

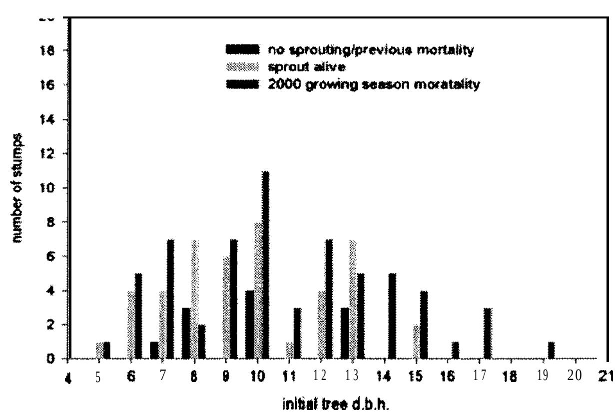

Figure 2-2000 diameter distribution of cherrybark oak sprouting success for light and heavy thinning treatments on the Red River Wildlife Management Area, Concordia Parish, LA.

Table l-Stump sprout characteristics two years after light and heavy thinning in a cherrybark oak plantation on the Red River Wildlife Management Area

Treat-ment	Sprout Success (percent)				No. Sprouts per Stump				Height (cm)				Ht. Growth (cm)	
	1999		2000		1999		2000		1999		2000		2000	
Light	79a[1]	1.1[2]	33a	4	8	1.1	10	1.7	60	4	79	13	12	9
Heavy	66b	3.4	44b	5	9	0.8	7	0.9	60	2	86	3	28	3
p-value	.0010		.0066		.9444		.3181		.9242		.6479		.2392	

[1] Numbers followed by different letters within a column are significantly different at p 0.05.
[2] The second column within each growing season represents ±1 standard error.

79 percent to 66 percent, respectively (table 1). Greater success in the light thinning may be attributed to a greater number of trees harvested in the smaller dbh size classes, especially the 6- and 8-inch dbh classes, with subsequent greater sprouting potential (figure 1). Greater sprouting for smaller-sized trees has been reported for other oak species (Johnson 1975, Golden 1999). Sprouting success differences also existed between blocks (initial tree stocking) although no discernable patterns existed.

Sprout success dropped considerably the second year after thinning (2000 growing season). Success was only 37 percent across the study site, a 200 percent decrease from the previous growing season (figure 2). Mortality was distributed across the range of dbh but was most pronounced in the 8- and lo-inch dbh classes (figure 2). The likely cause for this increased sprout mortality was the severe drought that occurred during the two-year study period. Rainfall totals at the Marksville, LA station (about 15 miles southwest of the Red River WMA) were 75 percent and 72 percent of normal for 1999 and 2000, respectively. Twenty-four sprouts (17 percent of the total number of stumps) perished during the second growing season. Many of these sprouts grew well during the early growing season with multiple flushes, flush lengths ≥ 1 foot, and leaves distributed along the stem of each flush-all signs of good sprout vigor. Unlike the previous growing season, success was greater in the heavy thinned plots compared to the light thinned plots, 42 percent to 32 percent, respectively (table 1). With a greater number of trees thinned, the heavy thinned plots may have had less below-ground competition with a subsequent greater amount of soil moisture available for the stump sprouts. Differences continued to exist in sprout success between blocks but, as with the 1999 growing season, no discernable patterns existed.

Gardiner and Helmig (1997) reported 100 percent survival of stump sprouts 1 year following light and heavy thinning in a 28-year-old water oak (Q. *nigra* L.) plantation. Survival decreased considerable by year 2 and followed a gradual decline through year 7. No differences in survival occurred between the thinning treatments until year 7 when survival in the heavy thinning was 23 percent greater than in the light thinning. Gardiner and Helmig (1997) attributed this difference to early crown closure and subsequent decreased light levels in the lightly thinned plots. Similar results, despite the heavy influence of the recent drought, are expected with cherrybark oak in the present study as the overstory canopy should close earlier in the light thinned plots. Golden (1999) reported only 13 percent of cherrybark oak trees had sprouts 3 years following clear felling in 0.8-acre openings. He attributed this low sprouting success primarily to the initial large tree sizes and subsequent large stump sizes. Sprouting success has been shown to decrease with increasing parent tree diameter (Johnson 1975), possibly due to the inability of suppressed buds to break through the thicker bark associated with larger trees or the inability of sprouts to produce enough food to keep the large root system alive.

Sprout Number

Sprout numbers per stump varied little between treatments and growing seasons (table 1). Sprout numbers averaged 8.5 across both years. Self-thinning within sprout clumps has yet to occur. Apparently, the aforementioned drought has had little effect on survival within sprout clumps compared to sprouting success.

Gardiner and Helmig (1997) noted that l-year-old water oak sprout clumps averaged 15 stems per stump. They also noted that thinning level did not affect the initial stem number per sprout clump. Their results showed considerable within-stump sprout mortality through the first 4 years before stabilizing at about 4 stems per sprout clump by age 7. A decrease in the stem number per sprout clump was not found with cherrybark oak during the 2 growing seasons. Longer term results are needed from the present study with cherrybark oak before more direct comparisons can be made with the sprout number per stump with water oak.

Height

Height of the tallest sprout within each sprout clump averaged 60 inches one year after thinning. Heights generally increased with increasing tree dbh ($r^2 = 0.68$ for simple linear regression), ranging from 48 inches for the 6-inch dbh class to 107 inches for the 20-inch dbh class (figure 3). Mean height increased to 82 inches following the 2000 growing season, although this represented a 27 percent decrease in height growth from the previous year. The trend of increasing heights with increasing dbh class

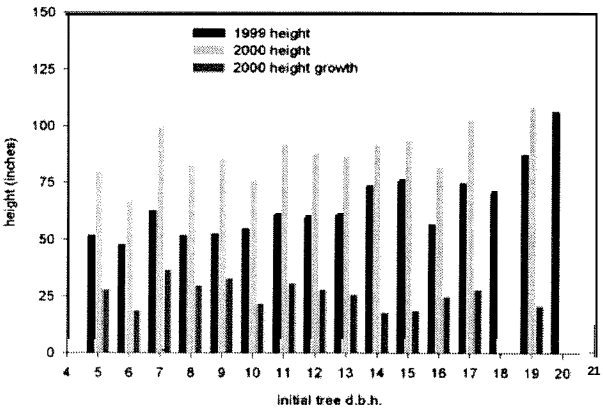

Figure 3-Distribution of 1999 and 2000 cherrybark oak sprout heights and 2000 cherrybark oak sprout height growth by dbh class on the Red River Wildlife Management Area, Concordia Parish, LA.

remained evident, though not as strong, in the second growing season ($r^2 = 0.42$, figure 3). Thinning regime did not influence sprout height during either growing season (table 1).

A pattern of decreasing height growth with increasing sprout age has been noted by others (Cobb and others 1985, Gardiner and Helmig 1997). Cobb and others (1985) found annual reductions in height growth of scarlet oak (Q. *coccinea* Muenchh.) sprouts ranged from 7-33 percent during the first 5 years of development following clearcutting in the upper Piedmont of South Carolina. Gardiner and Helmig (1997) also found sprout height growth decreased following thinning in a water oak plantation, from 20 inches annual growth for the first 5 years to 11 inches annual growth the next 2 years. Apparently, the rapid early height growth experience by sprouts decreases over time as the above-ground and below-ground portions of each sprout comes into balance.

CONCLUSIONS

Information on oak sprout development following partial cutting in southern bottomland forests is limited. Findings from this study with cherrybark oak in a thinned plantation are generally in agreement with Gardiner and Helmig's (1997) study of water oak sprout development in a thinned water oak plantation. Stump sprout success and growth are dependent on available resources. As these resources, especially light, diminish, slower growth and increased mortality should be expected. Therefore, future thinnings will be necessary to prolong the success and growth of these sprouts. Gardiner and Helmig (1997) mentioned thinning within sprout clumps could possibly extend sprout survival and growth, based on work conducted with upland oak species (Johnson and Rogers 1984, Lowell and others 1987). Such treatments require additional research with bottomland hardwood species.

Hart and others (1995) recent modification of Johnson's (1980) bottomland hardwood regeneration evaluation model gives 3 points for trees 2-5 inches dbh, 2 points for trees 6-10 inches dbh, 1 point for trees 11-15 inches dbh, and no points to trees ≥ 16 inches dbh. A minimum of 12 points is needed for a O.Ol-acre regeneration plot to be considered adequately stocked with regeneration or regeneration potential from stump sprouts. It would take 4 trees in the smallest dbh class or 12 trees in the 1 l-15 inch dbh class for a plot to be considered stocked, assuming no other trees were present in the plot. Data used in the modification of Johnson's (1980) model involved primarily seedlings and saplings; limited data existed for trees ≥ 4 inches dbh to adequately evaluate the role of stump sprouts in regenerating bottomland hardwood stands (Hart and others 1995, Belli and others 1999). Results from this study indicate that more weight should be given to trees in larger size classes, especially if drought induced mortality is removed. However, the present study was limited to only 141 harvested cherrybark oak trees growing on an excellent site which was subjected to unusual weather conditions over the past 2 years. Furthermore, the current bottomland hardwood regeneration model was developed for use in stands that will receive a regeneration harvest: the subsequent regeneration will respond to open conditions. The present study involved trees that were harvested as part of a thinning operation in which an overstory canopy still exists. Shading from this overstory will influence future development of oak sprouts. Also, sprouts in the present study arose from trees that were judged to be inferior to the residual trees; therefore, sprout development from these trees may differ from sprouts which develop from the residual crop trees. Much work remains on the role of stump sprouts in regenerating bottomland hardwood stands; this includes both oak and non-oak species.

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REPRODUCTION IN GROUP SELECTION OPENINGS 8 YEARS AFTER HARVEST IN A BOTTOMLAND MIXED HARDWOOD FOREST

Michael S. Golden[1]

Abstract-Eight-year reproduction was inventoried in permanent plots in 10 small patch cuts in a mixed bottomland forest by the Tombigbee River in western Alabama. Overall, there was adequate reproduction of commercial tree species (1174 stems per acre), but there were some scattered unstocked areas. The overall reproduction of oaks was relatively poor (an average of 340 per acre and less than 20 percent milacre plot stocking) and cherrybark, Shumard, and swamp chestnut oak reproduction was probably not sufficient to recover their proportions that existed in the preharvest overstory. Water/willow oaks were more successful than the other oaks and may attain equal or higher levels in the future stand compared to the preharvest overstory. Understocked areas in the patches resulted primarily from development of heavy woody vine and shrub cover, with grapevine the most important problem. The eight-year stocking of oaks originated primarily from advance reproduction less than one foot tall and from post harvest germination of acorns. The contribution of large advance oak reproduction was very small, due to the very low numbers present before harvest.

INTRODUCTION

The objectives of this paper are (1) to assess natural reproduction success for oaks and other major tree species eight years after harvesting small patches in a river bottomland mixed hardwoods forest; and (2) to examine the relative role of advance reproduction and post-harvest germination in establishing reproduction on this site.

STUDY SITE

The study was established in 1992 in a 75 acre stand of oak-dominated mixed bottomland hardwoods in the floodplain of the Tombigbee River, in Choctaw County, Alabama. The property is owned and managed by Ft. James Corporation. Physiographically, the site is in the Hilly Coastal Plain Province (Hodgkins and others 1979) and is just south of and downstream from the Black Belt.

At the time of cutting, the stand was predominately bottomland mixed oak forest, with the dominant canopy mostly 65-75 years old and 11 O-135 ft tall. The area of the study is a mixture of low, well-drained ridges and moderately to somewhat poorly-drained flats. The dominant soils are of the Mooreville, Urbo, and Una series. Surface horizons are mostly loam to silt loam. Typically, most of the sites are covered by river floodwater for brief periods once or twice during the winter and spring. The flats can also fill with water from rainfall, resulting in their having surface water l-3 inches deep even in late spring.

STUDY DESIGN

Rectangular clearcut patches of 0.8 acre, 132 by 264 ft, were the basic units of the study. These were small clearcuts, but this size falls within acceptable size limits for a group selection regeneration method (Smith and others 1996), since they approximate one tree height wide by two tree heights long. Ten patches, centered among clusters of larger dominants and oriented generally east-west, were delineated.

Five patches were randomly selected and harvested in early June, 1992 and the remaining five were harvested in early October, 1992. These were operational commercial harvests conducted by loggers contracted by Linden Lumber Company of Linden, Alabama. Trees were felled by chainsaws, delimbed and topped where they fell, and pulled by grapple skidders to one of two centrally-located loading decks. Following the commercial harvests, all remaining trees in the openings that were larger than 2 inches dbh were felled. When measured by remaining perimeter trees, all of the cut openings were slightly more than 0.9 acre in size. In aggregate, the ten cut patches totaled approximately 9.1 acres.

DATA COLLECTION AND ANALYSIS

Prior to harvest, all trees in each patch greater than 10 ft tall were inventoried and their locations mapped. Species and dbh were recorded for each tree.

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Table l-Preharvest stems per acre, basal area, and dbh's for trees larger than 5 inches dbh, all ten patches combined

Species	Stems/ac	Ft²/ac	DBH (in.) Mean	DBH (in.) Maximum
Quercus pagoda	14	46.7	23.6	44.5
Quercus phellos	6	20.6	23.3	38.7
Liquidambar styraciflua	28	20.2	10.6	29.3
Quercus nigra	6	17.6	21.2	40.4
Quercus michauxii	5	8.8	15.1	40.4
Quercus shumardii	1	4.3	22.5	31.1
Fraxinus pensylvanica	5	4.1	11.0	27.6
Celtis laevigata	5	3.3	10.3	20.5
Carpinis caroliniana	12	2.6	6.3	11.9
Quercus lyrata	1	2.1	16.0	32.8
Carya spp.	2	1.9	11.0	21 .o
Carya ovalis	1	1.5	4.1	16.6
Carya cordiformis	2	1.1	5.1	21.8
Carya ovata	2	0.9	8.2	18.1
Quercus laurifolia	<1	0.8	21.2	25.2
Nyssa sylvatica	2	0.6	7.7	12.1
Morus rubra	1	0.4	7.0	9.9
Ulmus Americana	1	0.3	6.8	10.0
Carya tomentosa	1	0.2	7.7	10.8
Ilex opaca	<1	0.2	8.9	12.6
Ulmus spp.	<1	0.1	6.1	6.7
Halesia diptera	<1	0.1	5.9	7.2
Ulmus alata	<1	0.1	6.3	7.4
Ilex decidua	<1	<0.1	6.3	7.2
Crataegus spp.	<1	<0.1	6.0	6.0
Totals	96	134.0		

For inventory and long-term monitoring of reproduction, seven systematically-placed belt transects, each 6.6 ft wide and extending from side to side perpendicular to the long axis, were established in each patch. These were segmented into 1 milacre (6.6 by 6.6 ft) subplots, with 20 subplots in each transect within the patch boundaries, for a total of 140 milacre subplots within each patch. The subplot corners were marked with wire pin flags, which were replaced by plastic pipe stakes after the harvests.

All non-vine woody species were tallied by species and size class within each subplot before harvesting and several times since. The forest surrounding the developing patches was commercially clearcut in late summer, 1999. The last reproduction plot inventory was conducted in early June, 2000, eight years after the first harvests. Tree reproduction in the milacre plots were re-inventoried by species and competitive position class. To characterize and discuss the eight-year reproduction, only those trees considered "non-overtopped" (NOT) were included. This category is composed of trees with no competing trees having live foliage directly overtopping the tip. This includes those judged "free-to-grow", with no taller trees intersecting a 90 degree exclusion angle with the apex at the growing tip (Smith and others 1996) and those with slightly taller, crowding trees nearby, but with no foliage directly overtopping them ("free tip"). It was felt that all of these had at least some chance of ultimately being in the canopy. In the third decade after harvest, cherrybark oak has been found to be able to gain dominance over sweetgums that had earlier crowded them and been taller (Clatterbuck and Hodges 1988). Those trees completely overtopped were excluded from the analyses, regardless of height, and considered to have lost the battle for space in the developing canopy.
At the eight-year inventory, several hundred of the original reproduction plots were judged too heavily damaged by the 1999 timber harvest and were omitted from further analyses. Data from the remaining 954 plots were summarized by species and competition class and compared to preharvest data from the same 954 plots and to the total preharvest overstory inventory.

RESULTS AND DISCUSSION

Preharvest Trees

Before harvest, the overstories of all of the patches were dominated in basal area by oaks. Taken together, the oaks averaged 100.9 ft² per acre. Cherrybark oak *(Quercus* pagoda Raf.) averaged the highest basal area (table 1). It was present in the overstory of all ten of the patches, with a minimum basal area of 17.7 ft^2 per acre and a maximum of 95.1 ft^2 per acre. However, most of the trees were large and its canopy numbers were relatively small, averaging only 14 stems per acre. Willow oak (Q. *phellos* L.) was second in overall dominance (20.6 ft^2 per acre), but it averaged only 6 stems per acre. Water oak (Q. *nigra* L.) was present in the overstories of all ten patches, but was fourth overall in basal area and averaged only 6 stems per acre. Swamp chestnut oak (Q. *michauxii* Nutt.) was present in nine of the ten patches, but was never a leading dominant. Shumard oak (*Q. shumardii* Buckl.) was a leading species in one patch and present in another, but was absent from the other eight patches. Two other oaks, overcup (*Q. lyrata* Walt.) and swamp laurel oak *(Q. laurifolia* Michx.) were present but were scattered and in very low numbers within the patches. Sweetgum (*Liquidambar styraciflua* L.) was third in species average basal area (20.2 ft^2 per acre) and first in average stem density with 28 per acre (table 1). It was present in all patches. Green ash (*Fraxinus pennsylvanica* Marsh.) and sugarberry (*Celtis laevigata* Willd.) were present in most of the patches, but were never among the dominant species.

Advance Reproduction

For the analyses and the discussion here, a broad interpretation of "advance reproduction" will be used, to include all seedlings, saplings, and smaller trees having high stump sprouting potential (Johnson 1993). It has been widely established that hardwood stumps decline in their probability for producing long-lived sprouts as their size increases (Sander and others 1984, Johnson 1993, Belli and others 1999, Golden 1999). A previous study of the sprouts originating on this site (Golden 1999) found that stumps from trees smaller than 12 inches dbh sprouted with high frequency, but those larger produced very few sprouts still alive three years after harvest. Consequently, all trees smaller than 12 inches dbh (including saplings and seedlings) tallied in the reproduction plots were included as advance reproduction. Small seedlings of water oak and willow oak were impossible to reliably distinguish, so all reproduction data for these two oaks will be treated as one class, "water/willow oak".

With all sizes taken together, advance reproduction (AR) of all commercial species combined averaged 12,572 per acre (table 2). Water/willow oak reproduction comprised the majority of these, averaging 7,594 per acre. Cherrybark oak was second in advance reproduction, at 1059 per acre. All other oaks combined averaged less than 100 per acre.

It is noteworthy that more than 95 percent of the advance reproduction for commercial species **was** less than 1 ft tall (small AR), with only 609 per acre taller than 1 ft (large AR) (table 2). For the oaks, only 0.5 percent (45 per acre) of their advance reproduction was taller than 1 ft. For the 952 reproduction plots, cherrybark oak averaged only 6 stems per acre more than 1 ft tall, with 4 per acre of these less than 3 ft tall. There were no cherrybark oaks found in the sizes taller than 3 ft but smaller than 5 inches dbh (table 2). Water/willow oak advance reproduction had somewhat more, but only 26 per acre in large AR, and all of these were less than 3 ft tall. Sweetgum and green ash each had more than 150 stems per acre in large AR, with the large majority of these less than 3 ft tall. Other commercial species, principally sugarberry and elms, comprised more than 230 large AR per acre (table 2).

The small number of large AR for the oaks was apparently due to the heavy shade at the seedling layer, which was created mostly by the midstory and understory layers. Small seedlings were able to establish from strong acorn crops, but failed to continue height growth once food reserves from the acorns were exhausted.

Tree Reproduction After Eight Years

Among the eight-year non-overtopped (NOT) reproduction, commercial tree species averaged 1174 stems per acre, with sweetgum the most abundant (422 per acre) and green ash (301 per acre) second (figure 1). Taken as a group, the oaks comprised about 29 percent (340 per acre) of the NOT reproduction, with water/willow oak having the highest numbers (242 per acre) (figure 1). Cherrybark oak was reduced to 85 NOT trees per acre, and the other oaks (swamp chestnut, shumard, and overcup) together averaged only 14 per acre.

Table 2—Advance reproduction, including all trees up to 12 inches dbh found in the reproduction plots, by size class

Size	Cherrybark Oak	Water/willow oak	Other oaks	Sweetgum	Green ash	Other commercial	Total commercial
				Trees/acre			
4" tall	480	2082	19	66	95	619	3361
>4"<12" tall	573	5486	64	83	503	1893	8602
>1'- 3' tall	4	26	7	112	153	153	453
3'- 10' tall	0	0	0	20	6	13	39
>10' tall - 5" dbh	0	0	4	18	3	50	75
>5"<12" dbh	2	0	2	21	0	17	42
Totals	1059	7594	96	320	760	2743	12572

Table 3-Comparison of oak advance reproduction density and stocking percentages (of 954 plots) to non-overtopped (NOT) reproduction eight years after harvest

Species	All AR	Large AR only	8 year NOT
	-----Stems/acre	(pct. stocking)------	
Cherrybark oak	1112 (37)	6 (1)	85 (6)
Water/willow oak	7977 (56)	27 (2)	242 (14)
Other oaks	101 (7)	14 (1)	14 (1)
Sweetgum	336 (20)	180 (11)	422 (29)
Green ash	798 (34)	70 (12)	301 (21)
Other commercial	2882 (83)	243 (18)	110 (10)

Comparisons Of Preharvest To Eight-Year Species Composition

Advance Reproduction Comparison-in terms of number per acre, when all advance reproduction sizes are taken together, the attrition in numbers from AR to 8-year NOT was most dramatic for water/willow oak, which declined from 7977 to 242 per acre (table 3), for a 33:1 ratio of AR to 8-year stems. This is not surprising, since only 27 per acre of the AR stems were taller than 1 foot. Cherrybark oak numbers also declined drastically, from 1112 to 85 per acre (13:1). Even fewer (6 per acre) of its AR were taller than 1 foot. Only sweetgum showed an increase, from 336 to 422 per acre (table 3).

However, published predictive methods for oaks emphasize that larger AR, at least 1 foot tall, have much higher probabilities for reproduction success (Sander 1984, Johnson and Deen 1993, Belli and others 1999). If only those larger AR are considered, the oaks increased their numbers substantially - cherrybark oak from 6 to 85 per acre and water/willow oak from 27 to 242 per acre. This clearly indicates that large AR alone did not account for the majority of successful oak reproduction.

One of the most informative values in assessing reproduction success is stocking percentage. From the practical standpoint of comparing importance of a species among tree reproduction, distribution is perhaps as important as sheer numbers, since having a given number of widely distributed seedlings is a more advantageous situation than when they are concentrated in dense clusters.

Distribution is customarily assessed in silvicultural applications by determining the percentage of well-distributed sample plots that are "stocked". This gives information that is highly related to both density and distribution. For a specific species, a stocked milacre reproduction plot had at least one suitable individual of the species present. Stocking for "all AR" was determined using presence of any stem less than 12 inches as the criterion, but stocking using just "large AR" (that less than 1 ft tall excluded) was also determined.

With all sizes considered, AR stocking for cherrybark oak was somewhat low (37 percent), while water/willow oak was moderate (56 percent), and other oaks was very low (7 percent) (table 3). The stocking with large AR oaks was extremely low (1, 2, and 1 percent, respectively, for cherrybark, water/willow, and other oaks). When AR stocking was compared to that of 8-year NOT, the data exhibited a pattern similar to that for stems per acre, differing primarily in degree. The ratio of all AR stocking to 8-year was about 6:1 for cherrybark oak, 4:1 for water/willow oak, and 7:1 for other oaks (table 3). Unfortunately, the stocking levels were very low in the 8-year stand for the oaks, only 6, 14, and 1 percent for cherrybark, water/willow, and other oaks, respectively. Again, sweetgum exhibited an increase from preharvest to eight-year stocking (table 3). So, using plot stocking as the criterion, oak reproduction success would be judged to be very poor.

Preharvest Overstory Comparison-Another test of reproduction "success" for a specific species is whether it held its own or increased in proportion compared to its proportion in the preharvest overstory. In other words, has a species gained or lost in relative importance in the new stand compared to the harvested one?

When the species proportions in the preharvest overstory (all trees more than 5 inches dbh) numbers were compared to their proportions among the 8-year NOT trees (figure 2), the greatest gain achieved was for green ash, which increased more than fourfold, from 5 to 22 percent of stems. Water/willow oak gained slightly (13 up to 17 percent) and sweetgum remained almost the same (about 30 percent). However, cherrybark oak and other oaks lost substantially in proportions, dropping to less than half and to one-eighth, respectively (figure 2). Cherrybark oak comprised only 6 percent of the 8-year NOT trees, down from 14 percent in the preharvest overstory.

Table 4-Sources of plots stocked with non-overtopped oak reproduction after eight years

Source	Cherrybark oak	Water/willow oak	Other oaks
	Number (pct.) of plots		
All AR, <12" dbh	37 (62)	104 (78)	0 (0)
AR, 1' tall-12" dbh	2 (3)	8 (6)	4 (40)
Post-harvest germination	21 (35)	21 (16)	6 (60)
Totals	60(100)	133(100)	10(100)

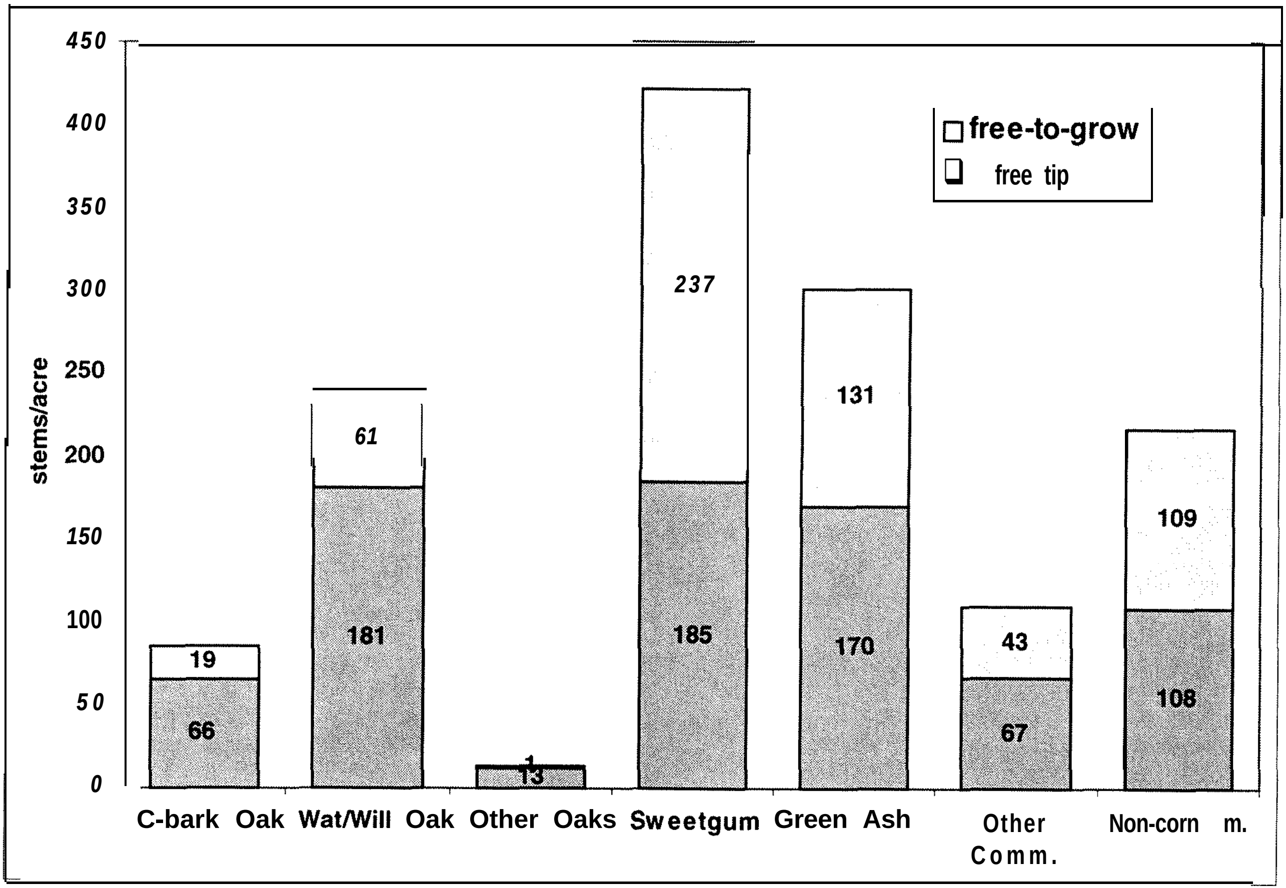

Figure l-Eight-year non-overtopped (NOT) reproduction.

Origins Of Eight-Year Oak Stocking

Since it was obvious from the previous analyses that most of the successful (non-overtopped) oak regeneration at eight years could not have come from large advance reproduction, where did it come from? Conventional wisdom is that oak regeneration must come almost entirely from advance reproduction, and so postharvest germination of seed plays little or no role (Johnson 1993). Although individual seedlings were not tagged in this study, the careful inventory of precisely relocated small plots allowed me to develop some conservative assessments of the role of post-harvest germination (PHG) in providing successful stocking at eight years.

For this, I examined for each oak species just those plots that were stocked with at least one NOT tree at the eight-year inventory. For these, if a plot had not been stocked with any size AR, it was assumed that the source of that plot's stocking at 8 years was PHG. If it had any AR, the stocking was assumed to have originated from that. For those stocked plots that had contained AR, they were assumed to have originated from large AR if any stems taller than 1 foot were present for the species at the preharvest inventory. Otherwise, they were assumed to have originated from small AR, less than 1 foot tall. Thus this approach produced estimates of PHG and small AR that are minimums relative to AR and large AR, respectively.

The results indicate that PHG contributed substantially to the eight-year NOT stocking for the oaks. For cherrybark oak, 35 percent of its stocking (21 of 60 plots) was from post-harvest germination (table 4). The proportion was smaller for water/willow oak, 17 percent, but still substantial. Only 10 plots were stocked with other oaks, but 6 of these were from PHG.

Most of the stocking for cherrybark and water/willow oaks originated from small advance reproduction, comprising 62 and 78 percent, respectively, of stocked plots (table 4). Only about 3 and 6 percent of the stocking originated from AR taller than 1 foot for cherrybark and water/willow oaks respectively. This is primarily a reflection of the lack of large advance reproduction in the stand.

Major Limitations To Successful Reproduction

Muscadine grape (*Vitis rotundifolia*) proved to be a major problem on this site. It did not appear to be particularly abundant before the harvest, although vines were common and small seedlings were scattered throughout. Between the three-year assessment (not reported) and the eight-year inventory, a large number of seedlings and saplings were completely covered by grapevines, and many were bent or even broken over by the weight of the heavy vines. Rattan-vine (*Berchemia* scandens) also covered and broke seedlings in some areas. Erect blackberries (*Rubus* spp.) formed tall, dense thickets in

Figure 2-Percentage of total stems, by species, for preharvest trees (>5" dbh) vs 8-year non-overtopped.

some areas. Some of these created sufficient shade to cause mortality of developing oaks. The blackberries also provided support for the woody vines, producing a tent-like effect in some areas.

CONCLUSIONS

Eight years after harvesting small clearcut patches in a riverbottom mixed forest, there was adequate reproduction of commercial tree species overall (1174 per acre), but there were some scattered unstocked areas. The overall reproduction of oaks was relatively poor (340 per acre and less than 20 percent milacre plot stocking) and cherrybark, Shumard, and swamp chestnut oak reproduction was probably not sufficient to recover their proportions that existed in the preharvest overstory. Water/willow oaks were more successful than the other oaks and may attain equal or higher levels in the future stand compared to the preharvest overstory. Understocked areas in the patches resulted primarily from development of heavy woody vine and shrub cover, with grapevine the most important problem. The eight-year stocking of oaks originated primarily from advance reproduction less than one foot tall and from post harvest germination of acorns. The contribution of large advance oak reproduction was very small, due to the very low numbers present before harvest.

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THE USE OF SOIL SCARIFICATION TO ENHANCE OAK REGENERATION IN A MIXED-OAK BOTTOMLAND FOREST OF SOUTHERN ILLINOIS

John M. Lhotka and James J. Zaczek[1]

Abstract-The purpose of the study was to investigate whether soil scarification following seed fall can be used to increase the density of oak regeneration in a mixed-oak stand. The study area was a 4.5-hectare stand dominated by cherrybark oak (Quercus pagoda Ell.). The understory had a high percent cover of poison ivy *(Toxicodendron radicans* (L.) Kuntze) and essentially lacked oak advance regeneration. In November 1999, the scarification treatment was accomplished using a tractor with a pull-behind field disk. One growing season after scarification, the number of oak seedlings was significantly higher in scarified plots (7,243/ha) than in the control plots (453/ha). Percent cover of poison ivy decreased from 36 percent to12 percent in the scarified plots. These results suggest that, in the presence of abundant acorns, scarification increased the likelihood of oak germination in a stand that lacked advanced oak regeneration prior to the treatment. Finally, because scarification increased the density of oak seedlings, it will increase the likelihood that mixed-oak stands can be successfully regenerated after a canopy disturbance.

INTRODUCTION

It is well documented that in order to regenerate oak stands a sufficient amount of competitive advance regeneration must be present before a harvest (Crow 1988, Johnson and others 1989, Meadows and Stanturf 1997, Zaczek and others 1997, Larsen and Johnson 1998). Understory treatments such as mechanical removal and chemical control of competition have been proposed to increase oak establishment and growth in bottomland oak forests (Crow 1988, Johnson and others 1989, Loftis 1990, Nowacki and others 1990, Bundy and others 1991, Nowacki and Abrams 1992, Zaczek and others 1997). Soil scarification is one other treatment that has been proposed (Scholz 1959, Bundy and others 1984, Crow 1988, Johnson and others 1989, Barry and Nix 1992, Zaczek and others 1997). Soil scarification may help to provide favorable germination conditions for acorns, protection from predators, and control competition (Crow 1988, Zaczek and others 1997) and therefore increase the likelihood of germination and development into a vigorous seedling.

Soil scarification may increase acorn germination and survival by incorporating the acorns into the soil (Zaczek and others 1997, Lhotka 2001). Acorn germination conditions have been shown to be more favorable below the soil surface than on the soil surface (Griffen 1971, Janzen 1971). In addition, acorns buried below the surface have been shown to be less susceptible to animal damage (Auchmoody and others 1994, Nilsson and others 1996). It is important to provide this protection because of high acorn predation rates (Auchmoody and others 1994, Steiner 1995). Because scarification helps to incorporate acorns below the surface, it may increase the chances that an acorn will germinate and develop into a vigorous seedling. Scarification may also help control competing vegetation. With a decrease in competing vegetation, newly established seedlings may gain a better competitive position and have an increased chance for successful development.

The purpose of the study was to investigate whether soil scarification, in the presence of abundant acorns, can be used to enhance oak regeneration in a mixed-oak bottomland forest. This paper reports the germination and survival of oak regeneration one year after soil scarification.

METHODOLOGY

The study was conducted in a 4.5-hectare mixed oak-hickory bottomland forest stand located in Saline County, Illinois. The overstory was composed of cherrybark oak *(Quercus pagoda* Ell.), shagbark hickory (*Carya ovata* [Mill.] K. Koch), mockernut hickory (*Carya tomentosa* [Poir.] Nutt.), and post oak (Quercus *stellata* Wang.). The understory was dominated by a thick blanket of poison ivy *(Toxicodendron radicans* [L.] Kuntze) and essentially lacked advanced oak reproduction.

Prior to scarification, eight linear transects to receive scarification were laid out within the stand. A total of fifty 1.77 m^2 plots were located along the center of the transects to measure existing vegetation. An additional fifty 1 m quadrats were located along the transects to measure the number of acorns and hickory nuts present prior to treatment. Unscarified control plots were paired with each scarified plot and were located 3.8 m from the center of the scarified transects (figure 1). The plots were allocated proportionally according to the length of the transect. All trees < 1.5 m in height were measured to the nearest 0.1 m. Percent cover of vine and shrub species were also

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Table l-The density (number per ha) of viable seeds by treatment and species group

Species	Density of Viable Seeds	
	Control	Scarified
All Oaks"	47,466	56,399
Hickory[b]	932	1,598

[a] All Oaks include: *Quercus bicolor* Willd., *Quercus michauxii* Nutt., *Quercus macrocarpa* Michx., *Quercus pagoda* Eli., *Quercus stellata* Wang.
[b] Hickory includes: *Carya ovata* (Mill.) K. Koch., *Carya tomentosa* (Poir.) Nutt.

measured at that time. The acorn crop was measured by using 1 m^2 plots placed directly adjacent to the center of each vegetation plot. At each acorn plot, acorns were tallied by species and a sample was collected to test for germination success.

Scarification was completed on November 5, 1999 using an International 464 tractor with an international 122 disk. The disk was approximately 2.44-meters wide. This International 122 is a standard-type field implement with rolling metal disks that help to penetrate the soil and mix the upper soil layer. Because the ground was very dry, the area was scarified by making three passes across the transects with the disk. The paired control plots were left undisturbed.

The overstory inventory was conducted in May 2000 using twenty 7.98 m radius plots. All trees >1.5 m in height and <9 cm DBH were measured. A relative importance value was then calculated for each species (Cottam and Curtis 1956). At each overstory plot,a 25 m^2 plot was used to measure all trees <1.5 m in height and less than 9 cm at DBH.

Table P-Tree Seedlings densities (stems per ha) by species, inventory date, and treatment

Species	Pretreatment Stems per ha		October 2000 Stems per ha	
	Control	Scarified	Control	Scarified
All Oaks"	566	453	453	7,243*
Acceptable Hardwoods[b]	3,778	5,206	4,640	10,072'

*indicates significant difference between treatments at alpha = 0.05
[a] All Oaks include: *Quercus pagoda* Ell., *Quercus stellata* Wang.
[b] Acceptable Hardwoods include: *Carya ovata* (Mill.) K. Koch., *Carya tomentosa* (Poir.) Nutt., *Comus racemosa* Lam., *Diospyros virginiana* L., *Fraxinus pennsylvanica* Marsh., *Ulmus americana* L.)(American elm), red elm, (*Liquidambar styraciflua* L., *Nyssa sylvatica* Marsh.) *Prunus serotina* Ehrh., Sassafras albidum (Nutt.) *Nees, Ulmus alata* Mic

In October 2000, understory vegetation was measured along transects using fifty randomly located 1.77 m^2 radius paired plots to reflect first year survival. The number of stems was summarized into four species groups (All Oaks, Acceptable Hardwoods, Total Tree Seedlings, and Poison Ivy). The pretreatment acorn number and regeneration density by species for each inventory were analyzed by using one-way analysis of variance (ANOVA) at an alpha = 0.05 to test for differences between the control and scarified treatments.

RESULTS

The stand had a mixed bottomland oak-hickory composition with a basal area of 28 m^2/ ha and a density of 365 stems / ha. The dominant overstory species were cherrybark oak, shagbark hickory, mockernut hickory, and post oak. Other species did not exceed 2.0 in importance value. The stand had a very sparse midstory canopy

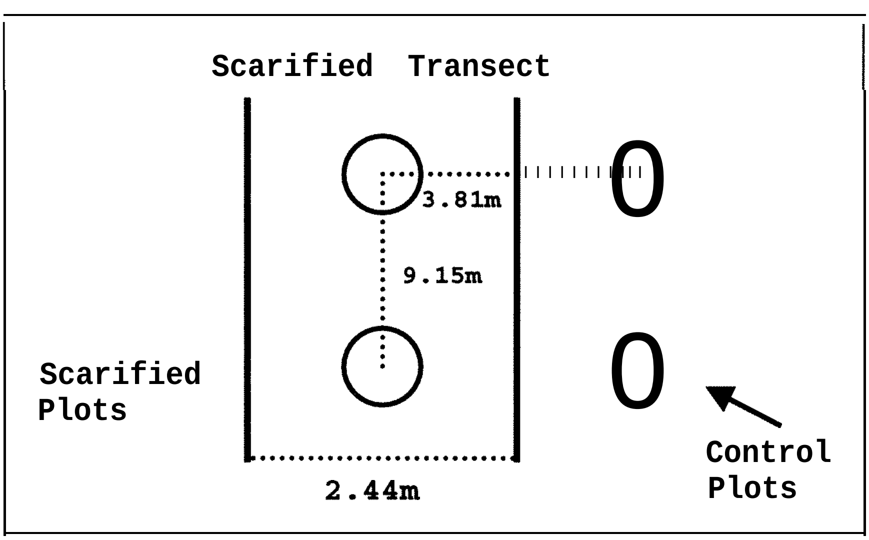

Figure l-Paired plot sampling design for understory vegetation inventory stratum and was comprised of only 280 total stems/ha. Of these stems, 57 percent were green ash *(Fraxinus pennsylvanica* Marsh.) and 21 percent were hickories (*Carya spp.*).

The prescarification vegetation inventories and acorn counts showed no significant difference between the control and scarified plots. The number of acorns ($F = 0.50$, $p = 0.4792$, $df = 1,99$) (table 1) and the number of total seedlings ($F = 0.25$, $p = 0.6167$, $df = 1,99$) were not significantly different between the control and scarified plots (table 2). The number of acceptable hardwoods in the scarified plots was also not significantly different ($F = 0.36$, $p = 0.5506$, $df = 1,99$) than the number in the control. The height distribution prior to treatment was spread across all height classes, but an increased frequency occurred in the classes shorter than 85cm. Also in the understory, the poison ivy cover was also not significantly different ($F = 0.10$, $p = 0.7570$, $df = 1,99$) between the control and scarified plots.

One year after treatment, the scarified plots had a higher seedling density than the control (table 2). The oaks, especially, had higher densities in the scarified plots. This large increase in oak in the scarified plots was related to increased germination rates. The germination percentage of viable acorns found in the scarified plots was 9 percent, while in the control plots the percent germination was near zero. As a result of the new germinants, the number of oaks was significantly higher ($F = 14.96$, $p = 0.0002$, $df = 1,99$) in the scarified plots than in the control plots. In addition, the number of acceptable hardwood species was significantly higher in the scarified plots. One year after treatment, the oaks composed 42 percent of all seedlings in the scarified plots, but only made up 9 percent of all seedling in the control. Unlike tree seedling density, the percent cover of poison ivy was significantly lower ($F = 26.43$, $p = 0.0001$, $df = 1.99$) in the scarified plots (12 percent) than in the control plots (36 percent).

Scarified plots also had fewer large seedlings than the control plots. In the control plots, 1,697 stems / ha occupied the height classes > 44 cm and 2,490 stems / ha were present in the lower two height classes (O-24 cm, 25-44 cm) and these stems were mostly green ash. Oaks only accounted for 14 percent of the total stems in the lower two height classes and only 7 percent of the total stems > 44 cm in height in the control plots. Unlike the control plots, the scarified plots only had 339 stems/ha (2 percent of total) present in the height classes greater than 44 cm. Ninety-eight percent of the seedlings in the scarified plots were less than 44 cm in height and 86 percent of the total stems are less than 25 cm in height. In the scarified plots, oaks accounted for 48 percent of all species in the O-24 cm height class and no oaks are greater than 24 cm in height.

DISCUSSION

The scarification apparently enhanced acorn germination even under severe predation pressure. Of the potentially viable acorns remaining at the time of scarification, the germination percentage in the scarified plots was 9 percent, while the control plots had no new germinants. Although the germination percentage in the scarified plots was somewhat low, even a small increase in germination percentage resulted in greatly increased numbers of oak recruits and the overall pool of advanced regeneration.

Past soil scarification research had similar early results to this study. A project conducted by Scholz (1959) used a disking method to improve the initial establishment of northern red oak. After the first year, the study showed an increase in northern red oak densities in the disk plots. In addition, a study conducted by Zaczek and others in 1997 found that higher proportions of acorns germinated in the scarified plots (28 percent) than in the control plots (2 percent). In addition, a significantly greater number of northern red oak and a lower number of red maple were found on the scarified plots when compared to the control plots. The current study had similar trends to what was initially found in the aforementioned studies, but the current study's acorn germination percentages were not as high as found in Zaczek and others (1997). However, it is difficult to strictly compare the studies because they were not conducted in same region, the same species were not involved, predation pressure varied, and the stands did not have the same environmental conditions.

In addition to enhancing germination, the scarification treatment also played a role in reducing the poison ivy cover in the understory. The reduced competition should free up resources necessary for enhanced oak seedling growth.

The results after one year of this study look promising. The understory condition was more favorable than prior to scarification as scarified plots had more oak advanced regeneration present. With regard to seedling height distribution, it also appeared the oaks made up a favorable proportion of the regeneration cohort present one year after scarification. Because oak made up a more favorable proportion of the stems in the understory and did not have an over abundance of larger seedlings to compete with, the stand was in a better condition to be regenerated. One well accepted guideline about regenerating oak is that to ensure success large competitive advanced regeneration must be present in the understory prior to harvest (Crow 1988, Johnson and others 1989, Meadows and Stanturf 1997, Zaczek and others 1997, Larsen and Johnson 1998). It appears that the scarification has resulted in greater numbers of oak seedlings in an enhanced competitive position.

However, the oak seedlings present in the understory do not guarantee successful regeneration. Many factors are important to consider to ensure the future development of the regeneration currently present in the understory. An important factor controlling the survival of these seedlings is the understory light levels (Crow 1988, Nowacki and Abrams 1992) as cherrybark oak and post oak are intolerant of shade (Krinard 1990, Stransky 1990). Competing vegetation may also play a role in impacting the growth of the newly establish oak seedling reproduction. If oak growth is not rapid enough to extend above the competition, a regrowth of poison ivy over time may retard the development of these newly established seedlings. Likewise, repeated deer browsing may have a negative impact on these newly established seedlings (Lorimer 1993).

We suggest that manipulation of the midstory or overstory is likely necessary to alleviate some of the problems created by low light levels (Janzen and Hodges 1985, Loftis 1990). Without a release, the seedlings present will most likely not survive and leaving the stand in a condition similar to what was seen prior to the scarification treatment. However, even a release treatment does not guarantee the survival of this newly established regeneration cohort.

CONCLUSIONS

The purpose of this study was to determine the effects of shallow soil scarification, in the presence of abundant acorns, on the germination and first year survival in a mixed-oak bottomland forest. One year after treatment, the number of oaks was significantly greater in the scarified plots than in the control plots. The results suggest that the soil scarification treatment method used created more favorable conditions for increased acorn germination and oak seedling survival. The results gained from this study not only extend the knowledge of soil scarification as a tool to enhancing oak seedling reproduction, but also suggest that this silvicultural treatment may be a useful management tool when applied in bottomland oak stands.

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PREPLANTING SITE TREATMENTS AND NATURAL INVASION OF TREE SPECIES ONTO FORMER AGRICULTURAL FIELDS AT THE TENSAS RIVER NATIONAL WILDLIFE REFUGE, LOUISIANA

John W. McCoy, Bobby D. Keeland, Brian Roy Lockhart, and Thomas Dean[1]

Abstract-As part of a study of oak planting techniques for bottomland hardwood afforestation we examined the natural invasion of woody species onto former agricultural fields at Tensas River National Wildlife Refuge. Three replications of 14 treatments were established as 0.4 hectare (1 acre) plots in a complete randomized block design. Combinations of these treatments were used to examine the effects of disking and distance from existing forest edges on natural invasions of woody species. Each one-acre plot was sampled with 4 subplots, 100 m^2 each, for all seedlings greater than 0.3 meters in height. A total of 18 woody species, dominated by elm(*Ulmus* sp.) (41 percent), ash(*Fraxinus pennsylvatica*) (25 percent), and sugarberry(*Celtis laevigata*) (21 percent), and with lower frequencies of honey locust(*Gleditsia tricanthos*), deciduous holly(*Ilex decidua),* persimmon(*Diospyros virginiana*), hawthorn(*Crataegus* sp.), sweetgum(*Liquidambar styriciflua*), and black willow(*Salix nigra*), were noted. The treatment with little or no disturbance, no till, had more individuals (814.6/ha or 325.8/ac) than the strip disked(SD)(643.7/ha or 257.5/ac) or disked(DD)(380.2/ha or 152.1/ac) treatments. These differences in invasion rates may have been related to several aspects of disking. Disking may eliminate existing agricultural rows and furrows reducing microtopographic variation, bury seeds too deeply, or expose seeds to drying. Distance from the forest edge also affected invasion rates with an average of 1038.8 individuals per ha (415.5/ac) between 129 - 259m, 635.1/ha (254.0/ac) between 260 - 406 m, and 301.3/ha (120.5/ac) at greater than 406 m. The nearest mature forest edge was 129 m distant. Woody invaders were found up to 640 m from the nearest forest edge. Although factors such as soil type, herbivory, and moisture influence the woody plant species found in these fields, initial disturbance and distance from the forest edge was shown to be important factors determining natural invasion success.

INTRODUCTION

Reestablishment of bottomland hardwood (BLH) forests throughout the Lower Mississippi River Valley (LMRV) has increased in the last 10 years. Interest in replanting BLH forests to agricultural fields arises from increased land availability associated with decreased farm products income and the understanding that only a small amount (2.8 million ha) of historical (10 million ha) bottomland hardwoods remain in the LMRV (National Research Council 1982; Hefner & Brown 1985). Over the past 10 years 77,698 hectares were planted to BLH species in Arkansas, Louisiana and Mississippi by the U.S. Fish & Wildlife Service, the U.S. Army Corps of Engineers, the Natural Resources Conservation Service, the Arkansas Game and Fish Commission, the Louisiana Department of Wildlife and Fisheries and the Mississippi Department of Wildlife Fisheries and Parks. More land (89,009 ha) is expected to be planted over the next five years by these same agencies (King and Keeland 1999).

Initially the main focus of these plantings was the establishment of hard mast species such as oaks and pecan with the expectation that light seeded species would invade naturally. Most stands were reforested to provide habitat for game species, but recently, land managers have realized that maintaining a diverse plant community is important to mammals and birds that live all or part of their lives in bottomland hardwoods (Daniel and Fleet, 1999). This realization has shifted the focus of reforestation efforts to include the planting of many additional tree species such as ash, sugarberry, sweetgum and baldcypress (King and Keeland 1999). But, the role that natural invasion will provide for increased diversity and structural complexity remains to be understood. Questions as to the extent that natural invasion can be counted on to provide additional species and increase the tree diversity and structural complexity of the developing stands remain unanswered.

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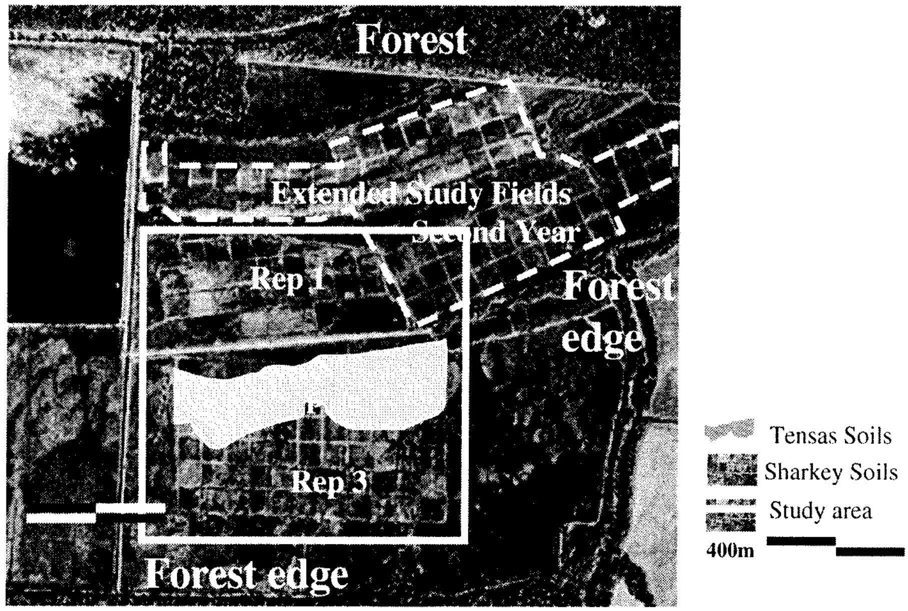

Figure l-Photograph of the Tensas River NWR study area (1995) showing the one-acre plots outlined by 10 m wide buffer strips. Forest edges for possible sources of seedlings are noted. Extended study fields are are part of a subsequent year study that are yet to be counted. North is to the top of the photograph.

In 1993 a reforestation study was jointly developed between the U.S. Fish & Wildlife Service, the Louisiana Department of Wildlife & Fisheries and the School of Forestry, Wildlife and Fisheries at Louisiana State University. The purpose of the study was to examine the establishment, survival and growth responses of selected oak species to several planting techniques. Over time additional woody species invaded the study plots and provided another aspect to the study. The purpose of this portion of the overall study is to examine the natural invasion of woody species onto these reforested areas to determine if the planting techniques (for the oaks) affected invasion rates.

METHODS

The study was conducted on the Tensas River National Wildlife Refuge (Tensas NWR) in northeastern Louisiana. The only topographic relief on the site consists of an old levee of the Tensas River. The levee runs east/west through the study area and is about 1 to 3 meters higher than the surrounding floodplain. Tensas soils, very deep, somewhat poorly drained, very slowly permeable, are found on the levee while Sharkey clay soils, very deep, poorly and very poorly drained, very slowly permeable, are found on the surrounding floodplain. The study area, which was fallow for less than one year before planting, was divided into one acre study plots (figure 1). Treatments were assigned as a randomized complete block design involving six direct seeding treatments as follows: (1) double disk, maximerge direct seed (DD); (2) double disk, maximerge direct seed, roll (DR); (3) strip disk, maximerge direct seed (SD); (4) no till, maximerge direct seed (NT); (5) single disk, cyclone direct seed, single disk (CS); (6) single disk, cyclone direct seed, single disk, roll (CR). The plots were direct seeded during the fall (October 1993) and spring (March 1994). Two oak species were planted, Nuttall (*Quercus texana*) and water oaks (Q. *nigra*), with one species per plot.

Two additional treatments (hand and machine planting of bare-root seedlings) were initiated December 1993. Each of the 14 treatments was replicated three times for each species producing a total of 84 treatment plots.

Fields were not bushhogged, but disking for selected treatments was accomplished in September 1993. Fall treatments were planted in October and spring treatments were planted in March 1994. All post-planting disking associated with cyclone direct seeding was accomplished immediately after planting. Seed and seedlings were kept chilled before planting (personal communication John Simpson, USFWS Tensas River NWR).

Each of the 84 one-acre study plots was sampled during November 1999 using 4 circular subplots, 100 m^2 each, established 20 m in toward the center from the corners of each field. All woody species greater than 0.3m in height was tallied from each subplot. Saplings were categorized by height into the following classes: (1) $>$ 0.3 to $<$ 0.5 m, (2) $>$ 0.5 to $<$ 1.0 m, (3) $>$ 1.0 to $<$ 1.4 m, (4) $>$ 1.4 meters to $<$ 2.5 cm diameter at breast height (DBH, at 1.4 m) and (5) all trees $>$ 2.54 cm DBH. Diameters were recorded only for those trees greater than 2.5 cm DBH.

Data on other woody perennial species such as *Sabal* minor (palmetto) was noted during the sampling. The dominant herbaceous species were noted for each plot, but a complete census of the herbaceous vegetation was not attempted. Data were analyzed by ANOVA using JMP (SAS 1988).

RESULTS AND DISCUSSION

Species Summary

A total of 4,496 individuals of 18 woody plant species, including the oaks, was observed on the plots (table 1). Average stem density across all plots was 541.9/ha (219.4 /ac) for invaders and 781.6/ha (316.4 /ac) for planted oaks. The presence of Nuttall oak, water oak on some plots where these species were not planted, and the presence of some willow oak (Q. *phellos*) on more than half the subplots suggests a possibility of acorn or seedling contamination at the time of planting. Willow oak was not one of the oak components.

Exclusive of the oaks, 1,821 stems were counted in all subplots, with three species groups dominating; elms (*Ulmus alata, U. Americana, and U. crassifolia,* 231.8/ha), ashes (*Fraxinus pennsylvatica,* 132.4/ha), and sugarberry (*Celtis laevigata,* 109.5/ha). These three species accounted for 85.1 percent of all naturally invading saplings encountered in the study. Frequency on subplots were 90.5, 61.9, and 86.9 percents for elm, ash, and sugarberry, respectively. These data show that not only were elms, ash, and sugarberry the most numerous species, but that they occurred on the greatest proportion of the plots. Elms and sugarberry were the most ubiquitous. Honey locust (*Gleditsia fricanfhos)* and deciduous holly (*Ilex decidua)* was also common, occurring on 30 and 36 percent of the plots, respectively. Although most species were fairly evenly distributed among and within plots, two species, hawthorns *(Crafaegus* sp.), and persimmons *(Diospyros virginiana),* exhibited clumped distributions. Sugarberry occurred in 47 percent of the plots and in 25 percent of the subplots as the only woody invader species. In general, those plots with sugarberry as the only woody invader were the furthest plots from the nearest forest edge. Elms occur in 72 percent of all subplots but never occurred without other tree species within a subplot. These occurrences are linked to distance but are also to related to soil type and herbaceous communities. Many of the dominant herbaceous plants act as perches for small songbirds and as such may help promote increased woody species density and diversity. These same herbaceous plants may also act as cover for rodents that feed on the seeds and seedlings.

Species Diversity

A total of 18 woody plant species invaded onto the study plots. The number of species may have been greater, but, due to the number of volunteers helping on the project, no attempt was made to identity hawthorns, or wild cherry to species. In addition, 31 elm saplings were listed as elm sp. on the data sheets. Forty two percent of the species, including boxelder, red maple, swamp dogwood, sweetgum, swamp cottonwood, saltbush, water hickory, and wild cherry make up only 3.6 percent of the saplings counted. The most abundant species, sugarberry, ash, and elms, make up 82.1 percent of the total number of individuals counted but are only 22.2 percent of the individual species represented within this study.

On average, 541.9 saplings/ha (219.4 /ac) were counted on the subplots. Twelve percent of all subplots at greater than 335 m from a forest edge did not have any invaders, but none of the one-acre plots were lacking natural invaders. In a previous study, where all tree seedlings were recorded, several 100 m^2 plots were empty (Allen and others, 1998). The proximity of these fields to a forest edge was a stronger influence on natural invasion rates than treatment effects ($p < .0001$). Several seedlings less than 30 cm were observed on many plots but were not counted as part of this study. It is probably that many more seedlings less than 30 cm tall were present but not counted.

All species encountered in this study, excluding the Prunus spp., are facultative to obligate wetland plants. Survival and growth of some species may have been affected by much less than average rainfall during the growing seasons of 1998 and 1999.

Herbaceous Vegetation

The herbaceous layer generally consisted of a mixture of herbs, grasses and vines similar to that reported by Allen and others, (1998). Most plots were dominated by one species or a combination of two to four species. Dominant herbaceous vegetation included *Solidago* sp. (24.0 percent relative frequency), *Lyfhrum salicare* (21.3 percent), *Campsis radicans* (12.7 percent), *Sorgham halapense (8.0* percent), and *Andropogon glomeratus* (7.14 percent). Several other relatively uncommon species noted on the plots included *Eupaforium* spp., *Verbena brasilensis*, and Aster spp. *Lyfhrum salicare* was the only observed species considered to be a noxious weed (Kartez, 1999).

Although some plants common to very wet areas, such as *Iva annua* and *Juncus effusis*, were found on the plots, their abundance may have been much less than is normal for this area. The drought of 1998 and 1999 (figure 2) caused many wet areas to dry out completely and probably had an impact on the herbaceous vegetation. It is possible that wet-site species may have been more abundant if the study has been conducted during a wetter time.

Although many areas were dominated by dense mats of vines such as *Rubus* sp., *Campsis radicans* and *Smilax* sp., these mats were generally small when compared with the plots size and were dispersed throughout the field. Other vines such as peppervine *(Ampleopsis arborea)* and grape (*Vitis* sp.) occurred sparingly within the fields.

Treatment Effects on Natural Invasion

Soil disturbance in the form of disking has been shown to have a significant effect on natural invasion rates (Allen and others 1998). In that study disking was shown to have a negative effect on the numbers of woody plants invading the plots. The effect of disking, however, appears to decrease through time(McCoy 1998). In the current study there were greater numbers of some species, especially the elms, on plots that had received little or no disking (SD or NT), but the effect was not significant when this study was sampled, at the end of the 6th growing season. None of the other silvicultural treatments examined in this study affected the rates of natural invasion by woody species. However, specific treatments that were positive for success of oaks were generally negative for the success of natural invaders.

Table l-Mean number of stems/ha by size class and species. Size classes are: Class 1- > 30 to c 50, Class 2- > 50 to < 100, Class 3- > 100 to < 140, Class 4- > 140 to < 2.5 cm diameter at 140 cm height (DBH), Class 5- > 2.5 cm DBH. Frequency and stem densities are given for all size classes combined.

	CLASS					Frequency		Stems	
Species	1	2	3	4	5	Abs.	Rel.	Total	per / ha
Box Elder	0.0	0.3	0.0	0.3	0.0	2.0	2.4	2.0	0.6
Red Maple	0.3	2.7	0.9	0.0	0.0	10.0	11.9	13.0	3.9
Baccharis	0.0	0.0	0.0	3.6	0.0	6.0	7.1	12.0	3.6
Water Hickory	0.0	0.0	2.4	0.3	0.9	6.0	7.1	12.0	3.6
Sugarberry	3.6	51.2	33.9	20.5	0.3	73.0	86.9	368.0	109.5
Swamp Dogwood	0.0	0.3	0.0	0.0	0.0	1.0	1.2	1.0	0.3
Hawthorn	1.5	3.9	0.6	0.6	0.0	14.0	16.7	22.0	6.5
Persimmon	0.0	1.8	1.8	5.1	0.3	10.0	11.9	30.0	8.9
Ash	0.0	8.6	30.7	89.3	3.9	52.0	61.9	445.0	132.4
Honey-locust	0.0	1.5	2.1	7.7	2.4	25.0	29.8	46.0	13.7
Deciduous holly	2.4	3.3	2.7	3.9	0.0	30.0	35.7	41 .o	12.2
Sweetgum	2.4	2.4	0.9	0.3	0.0	19.0	22.6	20.0	5.9
Swamp cottonwood	0.0	0.0	0.0	5.3	0.6	6.0	7.1	6.0	1.8
Wild cherry	0.0	0.0	0.0	0.0	0.3	1.0	1.2	1.0	0.3
Black willow	0.0	0.0	0.0	8.9	2.1	7.0	8.3	22.0	6.5
Elms	64.0	126.0	27.8	4.8	0.9	76.0	90.5	779.0	231.8
Total invaders	74.2	202.0	103.8	149.0	11.6	84.0	100.0	1821.0	541.9
Oaks	99.0	310.0	186.0	182.0	3.0	84.0	100.0	2626.0	781.5

Soils and elevation can also effect the establishment of tree species in old fields. In this study, greater numbers of sugarberry was found on the Tensas soil type along the natural levee of the Tensas River($p = 0.0458$).

Distance From Forest Edge / Seed Source

Distance from the nearby forest edge has been shown to have a significant effect on invasion rates (Allen and others 1998). A comprehensive analysis of the effects of distance on invasion rates is not possible in this study as no plots were closer than 129 m from the nearest forest edge and the subplot furthest from the forest edge was at a distance of 640 meters. We did, however, observe that the number of all invading species declined with increasing distance from the forest. Distances by quartiles (25, 50, and 25 percent of the individuals) showed 1038.8 individuals per ha (415.2/ac) between 129 - 259m, 635.1/ha (254.0/ac) between 260 - 406 m, and 301.3/ha (120.5/ac) at greater than 406 m. The numbers of subplots at each of the three distance regimes above were 45, 148, and 143.

General patterns of dispersal with distance, however, indicate differences for light versus heavy seeded species. Most (55.2 percent) light seeded species such as elms, ash, sweetgum, red maple, box elder, swamp cottonwood, and black willow occurred within 259 meters of the edge. Heavy seeded species seemed to follow one of two patterns. Species with the largest seeds, those usually transported by mammals, were typically found near the forest edge. This included species such as honeylocust and persimmon. Several species such as sugarberry, deciduous holly and hawthorns, usually transported by birds, were often found at greater average distances from the forest edge. Dispersal distances to be expected for any seed depends as much on the potential animals feeding on the seeds as on the seeds themselves (Johnson and others, 1985). However, soil type and therefore herbaceous communities associated with these soils differ with distance from the existing forest edge and could affect animal and bird use and seedling establishment rates.

Height classes and dbh

Overall, 51 percent of the saplings were less than 100 centimeters in height (table 1). The size class with the greatest number of saplings was 50-100 cm with 37.3 percent of all natural invaders. At the end of six growing seasons half the saplings were still at or below the average height of existing herbaceous vegetation and difficult to see at a casual glance. This makes the evaluation of afforestation success hard to measure and susceptible to seedling count errors. Even with a thorough search of the study subplots it is possible that some existing saplings were not observed or counted.

The short height of so many stems may be partially related to local browsing by deer and other herbivores. Many

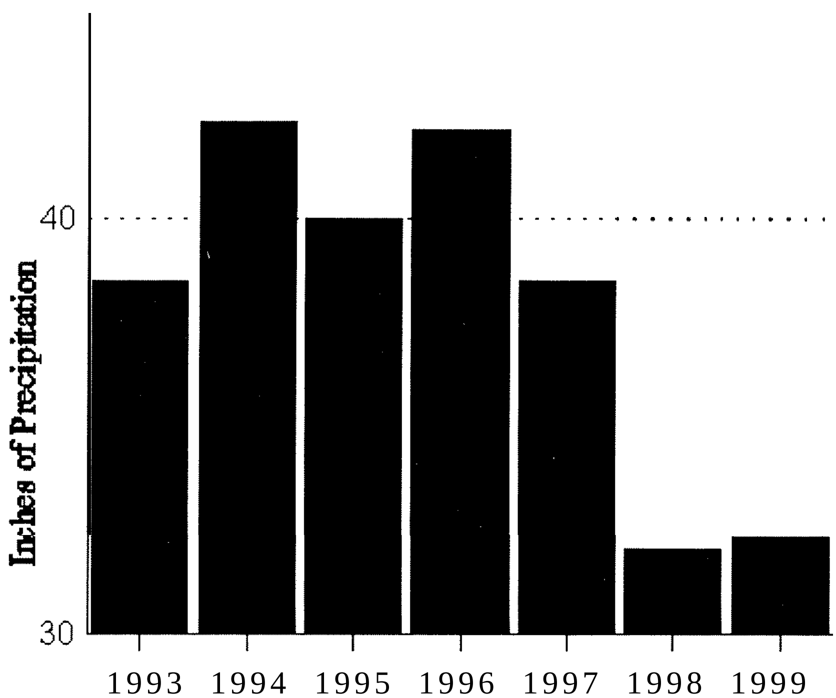

Figure P-Inches of precipitation for the region of Tensas River NWR.

saplings, especially the elms and sugarberry, had obviously been damaged by browsing. The lower than average levels of precipitation for the years 1998 and 1999 may also have affected the growth of many saplings (figure 2).

Only 541 saplings (29.7 percent) were in excess of 140 cm tall, and only 2.1 percent of the trees had a measurable diameter (greater than 2.5 centimeters DBH). The average DBH of these taller saplings was 3.9 cm. Black willow had the largest mean DBH, 4.8 cm followed by honeylocust at 4.3 cm. The only other species with substantial numbers of stems greater than 2.5 cm DBH was ash, with an average of 3.3 cm. These three, fast-growing species represent 72.4 percent of all stems greater than 2.5 cm DBH. The honeylocust sapling's size may have been aided by reduced browsing associated with the large thorns all along the stem and branches. Honeylocust is intolerant of shade (Burns 1990) which may help explain the lack of shorter individuals of this species.

The distribution of saplings among the five height classes was highly variable among species (table 1). Sugarberry stems were distributed among all size classes, but perhaps under represented in the smallest size class. This may have been due to browsing. The distribution of ash stems was skewed toward the taller size classes. The low numbers of ash stems in the shorter size classes may not be related to browsing as very few ash stems showed any signs of herbivory. Of the 20 sweetgums counted in the plots these were mostly limited to the smaller size classes, but, again this did not seem related to browsing. Elms dominated the smaller size classes with few large stems. Browsing was evident on most elm stems and was probably a large factor in the observed greater numbers of stems less than lm in height for this species.

CONCLUSIONS

Silvicultural planting treatments had little effect on the natural invasion of woody species onto these fields. Although some species, especially the elms, may be more numerous on plots with least disturbance (no till or strip disking) the effects were not significant at the 0.05 confidence level. The main factor affecting natural invasion rates was distance from the nearest forest edge. The effect of distance varied with species, seed size and disseminating agent (wind, birds, or other animals). Although the majority (75 percent) of most species with wind dispersed seeds were found within 392 m of the forest edge, some species with bird dispersed seeds were found in the most distant subplots, 640 m from the forest edge.

The effects of browsing on natural invasion and survival rates are not well understood. While many species, such as honeylocust, sweetgum, black willow and persimmon, appear not to have any browsing damage, other species, such as sugarberry, elms and the planted oaks, were heavily browsed. Browsing is probably having an effect on the successful establishment of many seedlings, but it appears that the species most heavily browsed are the ones invading in the greatest numbers. This level of browsing may not have an overall detrimental effect on the developing woody plant community as it may be promoting a more even species composition. .

Height of the herbaceous plant community must be explicitly considered when assessing the success of a reforestation effort. In this study and in Allen and others (1998) the herbaceous vegetation was about 1 - 1.2 meters in height. At least half the saplings were below this height making them difficult to observe without a concerted effort. Persons conducting an evaluation before five to six years post planting may have difficulty finding all saplings within the sample area.

Interactions of the different effects such as distance and direction from existing forest edges, soil types, and disturbance makes analysis of this data complex. Unknown effects that further complicate the analysis includes browsing, existing forest edge species composition, and local climatic effects. However, an understanding of natural invasions onto former agricultural fields is being refined as more studies are completed.

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COMPARING ALTERNATIVE SLASHING TECHNIQUES ON A MIXED HARDWOOD FOREST: 2-YEAR RESULTS

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Abstract-Regenerating commercially important species following the harvest of an existing mixed hardwood stand requires adequate advance regeneration of the desired species and control of competing vegetation. These objectives can be achieved by removing the noncommercial stems before or after harvesting. This study was designed to evaluate the efficacy of pre- and post harvest slashing alternatives and to assess cost differences between the alternatives. Four treatments (pre- and postharvest slashing, with and without herbicide stump treatment) and a control were selected. Each treatment was applied to a 120 feet x 120 feet plot within which measurements were taken on four l/l 0-acre subplots. Each treatment was replicated six times within the harvest area, resulting in a total study area size of 9.9 acres. Preliminary results indicate that there was little difference between treatments in the total number of stems.

INTRODUCTION

A primary concern in harvesting mixed hardwood stands in the central hardwood region is ensuring adequate regeneration of the preferred commercially important species such as oak. Often competition from undesirable trees is too great for the commercially important species to overcome.

One means of enhancing oak regeneration is to control the competing species by slashing either prior to or immediately following harvest operations. Little information is available, however, to assess the relative effectiveness of the various slashing alternatives. Loftis (1978, 1985) evaluated the effectiveness and costs associated with preharvest treatments in southern Appalachian hardwoods. The results suggest that four years after clearcutting, preharvest treatments reduce the number of stems of undesirable species and increase the portion of desirable species in the stand. Ten years after clearcutting, stands that had received preharvest treatments were dominated by single stems of desirable species and stocking was excellent. Stands treated after the harvest operation contained a smaller percentage of desirable stems.

The research reported by Loftis used the postharvest treatments as a check on the effectiveness of the preharvest treatments. Moreover, only preharvest treatments involved herbicide applications. The purpose of our study was to evaluate how a stand developed after clearcutting when a variety of pre- and postharvest treatments were applied.

OBJECTIVES

The primary goal of the study was to evaluate alternative slashing techniques following harvest in a mixed hardwood forest. Specific objectives were to 1) assess the effect of pre- and post-harvest slashing and herbicide stump treatment of noncommercial stems on species composition flowing a silvicultural clearcut and 2) compare the costs associated with the pre- and post-harvest treatments.

METHODS

The site selected for the study is located on the Oak Ridge Forestry Experiment Station and consists of a 17-acre watershed. Elevations in the south-facing drainage range from 970 to 1100 feet above sea level. The harvested forest was comprised primarily of oaks (59 percent), yellow-poplar (*Liriodendron tulipifera*) (14 percent), miscellaneous hardwoods (10 percent), and pine (6 percent).

Five treatments were developed forcomparison in the study:

1 Preharvest Slash only
2 Preharvest Slash with Herbicide Stump Treatment
3 Postharvest Slash only
4 Postharvest Slash with Herbicide Stump Treatment
5 Control.

The five treatments were applied to 120 feet x 120 feet (0.331-acre) plots within the watershed. This plot size was large enough to distinquish individual treatments from surrounding treatments while allowing for several replications within the 17-acre study area. Each set of five treatments form a replication.

The 0.331-ac plots were located in the study site with the northwest corner serving as the starting point. From this point, the northwest corner of the initial plot was located approximately 25 feet to the southeast. Subsequent corners were located at 120-foot intervals by traveling on lines parallel and perpendicular to the initial line. A total of

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Table l-Species distribution by treatment, all stems, 1998

Species	Preharvest Slash	Preharvest Slash Herbicide	Postharvest Slash	Post-Harvest Slash & Herbicide	Control
Yellow-poplar	49.9	36.6	36.6	30.9	37.5
Red Maple	16.0	23.0	18.9	15.5	16.8
White Oak	2.1	2.8	2.9	2.6	3.3
Red Oaks	2.3	2.8	2.2	3.5	1.9
Blackgum	9.6	7.5	11.8	5.7	6.5

30 plots were identified in the study site, representing 6 replications.

Within each plot, four l/1000-acre subplots were established for intensive sampling. These were located by running a line south 13 degrees east from the northern corner of each plot to establish the first subplot center. The remaining three center points were located by running a 60-foot line parallel to the boundary lines.

Plots were assigned to different replications by establishing groups of plots that were similar in terms of species composition, density, and location. A computer-generated design for incomplete blocks developed by Arnold Saxton of the Tennessee Agricultural Experiment Stations was used to assign treatments to plots.

The initial inventory was conducted on June 18-21, 1996. The inventory included all merchantable timber from 6 inches in DBH and above, with all sawtimber size hardwoods graded. All trees were measured within the subplots regardless of size during the last two weeks of September 1996. Data were recorded by 1 foot height classes up to 4 feet. Trees taller than 4 feet were classified into less than 1.5 inches DBH or larger than 1.5 inches DBH (exact DBH was recorded for this class).

Preharvest slashing was conducted on the designated plots during the first two weeks of October 1996. All stems greater than 1 foot in height were treated. On each plot, starting and ending times for treatment were recorded. The number of stems cut per plot was recorded as stems greater than or less than 1.5 inches DBH. Garlon 3A 50/50 with water and red dye was used on all noncommercial stumps in the plots designated as preharvest slashing and herbicide stump treatment. Start and stop times were recorded for herbicide application as well as the amount of herbicide used and the number of stumps treated.

The timber harvest operation was conducted from February 5 to April 30, 1997. Approximately 118.9 MBF (Doyle) of hardwood sawtimber, 7.0 MBF of pine sawtimber, 29.2 cords of hardwood pulpwood, and 9.0 cords of pine pulpwood were removed.

Postharvest slashing was conducted on the designated plots on August 1, 1997, with start and stop times recorded as well as the number of stems cut per plot. The stems were categorized by DBH (less than or greater than 1.5 inches). Postharvest slashing and herbicide treatment plots were treated on August 15, 1997. The stump treatment consisted of Garlon 4 50/50 with oil and red dye. As with the preharvest treatments, start and stop times were recorded for herbicide application as well as the amount of herbicide used and the number of stumps treated.

All subplots were remeasured two years after harvest (summer 1998) to assess the effectiveness of the various treatments. Similar data were collected as described above for initial measurements of the treatment plots: species and number of stems by height class up to 4 feet and by diameter class of stems greater than 4 feet.

Table 2-Species distribution by treatment, stems > 4 feet, 1998[a]

Species	Preharvest Slash	Preharvest Slash & Herbicide	Postharvest Slash	Postharvest Slash & Herbicide	Control
Yellow-poplar	22.8a	20.8ab	12.6c	15.8c	14.3c
Red Maple	13.1a	23.0b	18.9a	15.5a	25.5a
White Oak	0.2ab	0.2ab	0.6bc	0.7c	O.la

[a] Similar letters represent percentages that are not significantly different at a = 0.05.

Table 3—Average activity by treatment

Treatment	Cutting (# trees/acre)	Herbicide (# trees/acre)	Time (minutes)	cost ($/acre)
Preharvest	948		129	$25.65
Preharvest/Herbicide	1383	607	310	$94.39
Postharvest	308		121	$19.69
Postharvest/Herbicide	426	387	216	$57.64

RESULTS AND DISCUSSION

The results of the two-year data suggest that the four treatments may vary in their effects on species composition, although statistical analysis reveals few significant results. Table 1 depicts the total number of stems by major species that were counted on the subplots. Few discernible differences were identified by this preliminary analysis. Yellow-poplar and red maple *(Acre rubrum)* were the predominant species for all treatments and the control plots. Oaks comprised less than 7 percent of the stems for all treatments. Plots with herbicide treatments (both pre- and postharvest) contained a **larger** component of oaks than the control or non-herbicide treatments.

Examining species composition differences among the larger stems (> 4 feet) revealed some statistically significant differences among treatments. Table 2 lists the percent of all stems counted for the species of primary interest by treatment type. Preharvest treatments resulted in a significantly larger portion of the stems being comprised of yellow-poplar saplings. Conversely, postharvest treatments contained a significantly larger percentage of large white oak saplings than the control or preharvest treatments.

The cost results reveal that the preharvest treatments were significantly more expensive than the post harvest treatments for both non-herbicide and herbicide alternatives (table 3). These results are similar to those reported by Loftis (1978) and can be explained by the level of activity required in each plot. The work crews treated more than 3 times as many stems in the preharvest plots than they recorded in the postharvest plots. The harvesting activity resulted in many of the stems in the postharvest plots being severed before treatment was applied. As a consequence, less work was required after harvest-which reduced the costs considerably. Loftis (1978) noted, however, that an equally effective alternative could have been employed that would have reduced the preharvest treatment costs substantially. In the Oak Ridge study, similar modifications in the treatments would reduce costs as well.

No conclusions can be drawn, however, regarding the cost-effectiveness of the alternatives. Although the preliminary results suggest that postharvest treatments have resulted in desirable species comprising a greater **percentage of** the larger stems than in the preharvest treatments, it is too early to conclude that this will continue throughout the life of the stand. Loftis (1985) reported that desirable stems in plots receiving postharvest treatments were beginning to be replaced by undesirable sprouts **in many instances by** year 10. If similar patterns emerge in the Oak Ridge stand, the cost-effectiveness of the alternatives could change significantly.

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SEVENTEEN-YEAR GROWTH OF CHERRYBARK OAK AND LOBLOLLY PINE ON A PREVIOUSLY FARMED BOTTOMLAND SITE

Warren D. Devine, John C. Rennie, Allan E. Houston, Donald D. Tyler, and Vernon H. Reich[1]

Abstract-This study documents the effects of cultural treatments on 17-year growth of cherrybark oak (*Quercus pagoda* Raf.) and loblolly pine (*Pinus taeda* L.) planted on a previously farmed bottomland site in southwestern Tennessee. Yellow-poplar (*Liriodendron tulipifera* L.) was part of the original study, but was excluded due to very high mortality in early years. The experiment was a randomized, complete-block design located on a former soybean field prone to occasional flooding. Cultural treatments were third-year fertilization (nitrogen and phosphorus) as well as disking and mowing for weed control. Natural regeneration as a means of afforestation also was investigated. Survival after 17 years averaged 64 percent for cherrybark oak and 63 percent for loblolly pine. Mean total height was 34.0 feet for cherrybark oak and 55.0 feet for loblolly pine. The mean diameters at breast height (DBH) of cherrybark oak and loblolly pine were 4.1 and 10.2 inches, respectively. Survival, height, and DBH of both species were not significantly affected by fertilization, mowing, or disking, nor were there any significant interactions among the treatments. Natural regeneration resulted in dense stands (4,340 trees per acre) dominated by small-diameter sweetgum (*Liquidambar styraciflua* L.).

INTRODUCTION

A number of studies have investigated afforestation of abandoned agricultural wetlands in the Mississippi Valley, but few studies have provided long-term results of afforestation practices on these sites. A plantation in southwest Tennessee provided the opportunity to observe seventeen-year effects of cultural treatments on a highly desirable bottomland hardwood species and an adaptive pine likely to perform well on such sites.

Cost share programs such as the Conservation Reserve Program and the Wetland Reserve Program have encouraged afforestation of farmed wetlands. The cultural practices used on these sites to improve early growth and to insure dominance of tree seedlings have varied. Mowing or disking for weed control is not as common today as in the past, but it is still important to understand the residual effects of these establishment practices on bottomland plantations. The primary objective of this study was to determine the suitability of cherrybark oak and loblolly pine for planting on a previously farmed bottomland site, and to evaluate the effects of cultural treatments on their establishment and growth. The planted plots in this study also were compared to a naturally regenerated area on the same site.

METHODS

The study took place on the Ames Plantation in Fayette County, Tennessee, 50 miles east of Memphis (35” 07’ N and 89” 19’ W). The site was a former soybean field on a floodplain of the North Fork of the Wolf River. According to the USDA Natural Resources Conservation Service county soil map, soils are of the Waverly (Coarse-silty, mixed, acid, thermic Typic Fluvaquents) and Falaya series (Coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents) (Flowers 1964). The Falaya series consists of somewhat poorly drained silty and sandy alluvium, and the Waverly series is a poorly drained silty alluvial soil. The study site had been in cultivation for more than 20 years prior to the establishment of hardwoods in 1981. Mean annual precipitation is 53 inches (Flowers 1964).

In spring of 1981, 1-O seedlings were hand-planted among the previous year’s soybean stubble at a 10- x lo-foot spacing. The study initially included 1,200 each of cherrybark oak, loblolly pine, and yellow-poplar seedlings. However, the yellow-poplar suffered very high mortality and was excluded from the study after the first 2 years.

The experiment was a randomized, complete-block design with a strip-plot treatment arrangement and four replications. Main plot treatments were arranged in a 2 x 3

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factorial composed of fertilized and unfertilized plots of the 3 species. The fertilization treatment was 150 pounds per acre nitrogen (ammonium nitrate) and 35 pounds per acre phosphorus (triple super phosphate) applied at the beginning of the third growing season. Three treatments were tested on the sub-plot level: disking, mowing, and no weed control. One-way disking and mowing were repeated as needed (three to five times annually) until the end of the fifth growing season to control competing vegetation. The plantings were never thinned. A 1.2-acre section of the same soybean field was left to regenerate naturally.

In January 1998, 17 years after planting, total height of each surviving tree was measured with a Haga altimeter. Diameter at breast height (DBH) was measured with a caliper. In the naturally regenerated area, 10 circular, 0.01-acre plots were randomly placed. Height, DBH, and species were recorded for each stem on these plots greater than 4.5 feet in height. Equations developed by Matney and others (1985) and Baldwin and Feduccia (1987) were used to estimate total bole volumes of individual trees outside bark. Stand volume estimates ($feet^3$ per acre) were calculated based on estimated tree volumes, survival rates, and planting density. Survival and growth data were analyzed by Analysis of Variance (ANOVA) using Proc Mixed in SAS (SAS Institute Inc 1997). Survival data were transformed with the arcsine-square root transformation to meet the normality and homoscedasticity requirements of ANOVA. Post-ANOVA mean separations were made with single degree of freedom contrasts (alpha = 0.05).

RESULTS AND DISCUSSION

Survival for cherrybark oak averaged 89 percent after 1 year, 77 percent after 2 years, and 64 percent after 17 years. Loblolly pine survival averaged 80 percent, 74 percent, and 63 percent after 1, 2, and 17 years, respectively. Fertilization and weed control treatments did not significantly affect survival at any age for either species (table 1).

Seventeen-year height, DBH, basal area, and stand volume for both species were not significantly affected by fertilization or weed control treatment, nor were there any significant treatment interactions. Although there were numerical differences among some of the treatment means, the variability of cherrybark oak height and diameter among blocks (replications) prevented any statistically significant differences. Loblolly pine had consistent height and diameter among both blocks and treatments, but survival rates varied widely among blocks.

Cherrybark oak had a mean height of 34.0 feet and a mean DBH of 4.1 inches after 17 years (tables 2 and 3). Because cherrybark oak it best suited to well drained soils (Krinard 1990), the poor drainage on parts of the study site may have hindered growth and root development. It is likely that soils in this study were more variable than indicated by the county soil map (Flowers 1964). A neighboring bottomland study in which soils were evaluated showed wide variations in soil properties including drainage over distances of less than 100 feet (Devine and others 2000). Even minor variations in soils can have major impacts on the success of planted hardwoods (Kormanik and others 1999). Due to the slow growth rate of the cherrybark oak, the 17-year-old plantation still had not formed a canopy sufficient to shade out competition. Several areas were heavily infested with Japanese honeysuckle *(Lonicera japonica Thunberg)* and other herbaceous and woody weed species. There was a visible reduction in woody competition on plots which had been disked or mowed, but this did not translate into a significant increase in growth for the plantation trees.

Cherrybark oak averaged 32.8 $feet^2$ per acre basal acre after 17 years of growth (table 4). The potential merchantability of this stand will depend on whether growth rates increase in the near future. On some of the plots, enough woody competition had already become established to make the planted trees a relatively minor component of the stand. Clatterbuck and Hodges (1988) noted that cherrybark oak reached its maximum growth rate later than sweetgum and eventually exceeded it in height. It is possible that this could occur in the present study because sweetgum is the predominant co-occurring species.

Table l-Survival after 1, 2, and 17 years for planted cherrybark oak and loblolly pine under six different treatment combinations[a]

Species/ Fertilization/ Weed Control	Age 1	Age 2	Age 17
		Percent	
Cherrybark oak			
Unfertilized/ None	88	73	62
Unfertilized/ None	88	78	72
Unfertilized/ Mowed	88	70	66
Fertilized/ None	91	81	66
Fertilized/ Disked	94	80	60
Fertilized/ Mowed	89	79	57
Lobolly Pine			
Unfertilized/ None	73	68	45
Unfertilized/ None	86	74	72
Unfertilized/ Mowed	80	80	66
Fertilized/ None	79	73	54
Fertilized/ Disked	81	77	66
Fertilized/ Mowed	83	76	76

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

Table P-Height after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark Oak	Loblolly Pine
	----- Feet -----	
Unfertilized/None	30.4	53.7
Unfertilized/Disked	37.1	56.1
Unfertilized/Mowed	33.3	56.5
Fertilized/None	32.8	52.3
Fertilized/Disked	34.6	56.0
Fertilized/Mowed	35.8	54.3

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

By year 17, loblolly pine had reached a mean DBH of 10.2 inches and a mean total height of 55.0 feet. Diameter and height growth was quite consistent among all treatments, and the plots had long since formed a closed canopy. At age 17 there was virtually no weed competition present in the pine plantings. Basal area averaged 160.9 ft^2 per acre for all treatments. Variations in basal area and stand volume of loblolly pine in tables 4 and 5 are a reflection of variation in survival among treatments and not of variation in growth. However, because survival rates varied widely among replications, there were no statistically significant differences in basal area or stand volume due to treatments. Hopper and others (1993) found that weed control, but not fertilization, increased growth and survival at age 4 of loblolly pine, sweetgum, and green ash (*Fraxinus pennsylvanica* Marsh.) planted on a West Tennessee bottomland site. Hunt and Cleveland (1978) also found that disking, but not fertilization at planting, increased height growth of loblolly pine through age 5. If differences in growth of loblolly pine due to weed control or fertilization were present early in the current study, they have since disappeared.

Table 3—DBH after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark oak	Loblolly Pine
	······ Inches ······	
Unfertilized/None	3.5	10.0
Unfertilized/Disked	4.7	10.1
Unfertilized/Mowed	4.3	10.3
Fertilized/None	3.7	10.3
Fertilized/Disked	4.4	10.3
Fertilized/Mowed	4.2	09.9

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

Table 4—Stand basal area after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark Oak	Loblolly Pine
	···· $Feet^2$ per acre ····	
Unfertilized/None	25.0	110.2
Unfertilized/Disked	42.8	179.7
Unfertilized/Mowed	41.7	171.2
Fertilized/None	23.1	142.3
Fertilized/Disked	32.5	170.7
Fertilized/Mowed	31.4	183.2

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

On disked plots of both species, 6- to 12-inch deep depressions were present between the tree rows. These depressions were accompanied by small ridges in line with the rows. Both features were likely caused by compaction and heaving of soil that resulted from disking. During wet periods, water ponded in the majority of these depressions, most notably those in poorly-drained areas. These depressions were still present 12 years after the plots had last been disked.

Natural regeneration resulted in dense stands (4,340 trees/acre) of sweetgum (74 percent of stems), boxelder (*Acer negundo* L.) (12 percent), red maple (*Acer rubrum* L.) (11 percent), and other hardwoods. Over 99 percent of the stems in this stand were less than 5 inches in DBH, and 46 percent of the stems were less than 1 inch in DBH. Species composition of this stand was heavily influenced by the adjacent, mature forest stands. The naturally-regenerated stand clearly had low potential for merchantability at age 17.

Table 5-Stand volume (total bole) after 17 years for planted cherrybark oak and loblolly pine under six treatment combinations[a]

Fertilization/ Weed control	Cherrybark Oak	Loblolly Pine
	···· -$Feet^3$ per acre- ····	
Unfertilized/None	469	2,953
Unfertilized/Disked	895	4,965
Unfertilized/Mowed	744	4.788
Fertilized/None	553	3,455
Fertilized/Disked	629	4,726
Fertilized/Mowed	630	5.008

[a] There were no significant differences among treatment combinations for either species at alpha=0.05.

CONCLUSIONS

Loblolly pine planted on a bottomland soybean field with no site preparation established a well-stocked stand by age 17. Cherrybark oak plots showed inconsistent growth, perhaps due to variations in soils. A single application of N and P fertilizers at year 3 did not increase growth of cherrybark oak or loblolly pine, nor did mowing or disking for weed control. Since disking resulted in depressions between tree rows still present 12 years after the site was last disked, its usefulness as a method of weed control on flood-prone or poorly-drained sites is questionable. The depressions increase the amount of time that water ponds on the soil which can be detrimental to the growth and survival of planted tree species not adapted to periods of extended flooding. Composition of natural regeneration on the former soybean field depended on neighboring stands and did not produce merchantable trees after 17 years.

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